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MORE FIGHT–LESS FUEL: REDUCING FUEL BURN THROUGH GROUND PROCESS IMPROVEMENT

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Aligning fiscal policies with energy conservation initiatives and operational requirements is vital to achieving a positive and sustainable energy outlook for the United States Navy. The purpose of this study is to fill critical gaps in current military aviation energy conservation research. To date, such research has failed to incentivize and reward individual aviation squadrons to conserve. Commercial aviation uses collaborative decision-making (CDM) tools to minimize costs associated with aircraft delays. Embracing a lean approach to operational management, the commercial sector has refined communications between air carriers, airport operators, ground handlers, and air traffic control. This study suggests applying commercial CDM frameworks to all of Naval Aviation to increase efficiency and operational effectiveness. Specific analysis includes the impact of ground resource capacity management, airfield demand analysis (slot arrival system) and demand management cost analysis on F/A-18 Hornet squadrons.

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MORE FIGHT–LESS FUEL: REDUCING FUEL BURN THROUGH GROUND PROCESS IMPROVEMENT

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Submitted in partial fulfillment of the requirements for the degree of

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ABSTRACT

Aligning fiscal policies with energy conservation initiatives and operational requirements is vital to achieving a positive and sustainable energy outlook for the United States Navy. The purpose of this study is to fill critical gaps in current military aviation energy conservation research. To date, such research has failed to incentivize and reward individual aviation squadrons to conserve. Commercial aviation uses collaborative decision-making (CDM) tools to minimize costs associated with aircraft delays. Embracing a lean approach to operational management, the commercial sector has refined communications between air carriers, airport operators, ground handlers, and air traffic control. This study suggests applying commercial CDM frameworks to all of Naval Aviation to increase efficiency and operational effectiveness. Specific analysis includes the impact of ground resource capacity management, airfield demand analysis (slot arrival system) and demand management cost analysis on F/A-18 Hornet squadrons.

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TABLE OF CONTENTS

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LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

Air-ENCON	Naval Aviation Energy Conservation
ATC	Air Traffic Control
ATM	Air Traffic Managers
AVDLR	Aviation Depot Level Repairable
BUNO	Bureau Number
CAASD	Center for Advanced Aviation System Development
CDM	Collaborative Decision-Making
CNAF	Commander, Naval Air Forces, U.S. Pacific Fleet
CNO	Chief of Naval Operations
CO	Commanding Officer
CSFWP	Commander, Strike Fighter Wing, U.S. Pacific Fleet
CVW	Carrier Air Wing
DECKPLATE	Decision Knowledge Programming for Logistics Analysis and Technical Evaluation
DoD	Department of Defense
DON	Department of the Navy
DSB	Defense Science Board
DSS	Decision Support System
EIA	Energy Information Administration
Eurocontrol	European Organization for the Safety of Air Navigation
FAA	Federal Aviation Administration
FBCF	Fully Burdened Cost of Fuel
FHP	Flying Hour Program
FIDS	Flight Information Display System
FRTP	Fleet Readiness Training Plan
FRS	Fleet Replacement Squadron
GDP	Ground Delay Program
GSA	General Services Administration
IATA	International Air Transport Association
I-ENCON	Incentivized Energy Conservation

IOC	Initial Operational Capability
IRTC	Intuitive Research and Technology Corporation
MIT	Massachusetts Institute of Technology
MO	Maintenance Officer
NAF	Naval Air Facility
NAS	National Airspace System
NAS	Naval Air Station
NASA	National Aeronautics and Space Administration
NASL	Naval Air Station Lemoore
NAVAIR	Naval Air Systems Command
NAVFLIRS	Naval Aviation Flight Record Subsystem
NEXTOR	National Center of Excellence for Aviation Operations Research
NPS	Naval Postgraduate School
OAG	Official Airline Guide
ODSS	Operational Decision Support System
OPNAV	Office of the Chief of Naval Operations
OPSO	Operations Officer
RBS	Ration-by-Schedule
RFT	Ready for Tasking
SCS	Slot Credit Substitution
SEMPCI	Shipboard Energy Management and Cold Iron Program
SHARP	Sierra Hotel Aviation Readiness Program
SIMIO	Simulation Modeling Framework Based on Intelligent Objects
SMA	Surface Movement Advisor
SOA	System Operations Advisor
SPADE	Supporting Platform for Airport Decision Making and Efficiency
TACAIR	Tactical Air
TFM	Traffic Flow Management
TMR	Total Mission Requirement
UAL	United Airlines
UAV	Unmanned Aerial Vehicle
USD	Under Secretary of Defense

I. INTRODUCTION

> We are operating in challenging fiscal and operational times, and we must take appropriate action now to ensure the current and future vitality of Naval Aviation. To successfully achieve our missions today and in the future, all Naval Aviation stakeholders must be in sync and focused on the common goals of advancing readiness while reducing costs.

VADM D. Buss, Commander, Naval Air Forces, April 30, 2013

A. BACKGROUND

According to the Department of the Navy's (DON) *Energy Vision for the 21st Century* (2012), a combination of reducing fuel consumption and increasing fuel efficiency is necessary to improve energy security. Furthermore, aligning fiscal policies with energy conservation initiatives and operational requirements is vital to achieving a positive and sustainable energy outlook for the Navy. In this post-war environment, the Navy must address fiscal and energy problems propagated by strong cultures of inefficiency and waste. The solutions proposed in this MBA project require no financial outlay. However, what is necessary is strategic thinking in a new and creative way. Leveraging existing infrastructure, proven commercial and military best practices, and motivation for cultural change will ensure Naval Aviation is ready to execute.

Until the Navy announced its new energy conservation platform in 2009, Naval Aviation has faced the challenge of managing both time and resources. For decades, Naval Aviation's policies, awards, metrics, and incentives focused on flight hour execution (time) with little regard to the amount of personnel, equipment, and fuel necessary to accomplish the mission. Former Commander, Naval Air Forces (CNAF), Vice Admiral Allen Myers, called for a philosophical change in operations by reducing fuel consumption measured in gallons without any change in the number of flight hours allocated (Commander, Naval Air Forces [CNAF], 2010). Each organization within Naval Aviation is to critically evaluate all practices and processes in search of inefficiencies and waste.

In 2012, tactical aircraft accounted for 65 percent of all fuel consumed by Naval Aviation (M. Olszewski, personal communication, May 29, 2013). Moreover, F/A-18 strike fighter aircraft consumed over 52 percent of the total aviation budget in 2012 using 334 million gallons of fuel alone (M. Olszewski, personal communication, May 29, 2013). Now, in concert with Admiral Myers' direction, many fuel-conserving ideas are underway including addressing the overarching framework in which the Navy manages its flight and ground operations. This framework must be designed from the ground up to incentivize and reward individual squadrons to conserve.

Problems related to inefficiency and waste in ground and flight operations extend well beyond the F/A-18 community. Rounding out the top ten fuel-consuming aircraft in the Navy include the P-3, AV-8B, H-60/H-1Y, C-130, EA-6B, CH-53, T-45, E-6, and V-22 (M. Olszewski, personal communication, May 29, 2013). Each community stands to benefit greatly from the solutions offered in this paper. Although fuel consumption per sortie is an important metric to evaluate, one must also consider the volume of flight operations a particular community executes, the internal fuel capacity, sortie length, engine burn rate, and maintenance costs. Regardless of the aircraft flown, all naval air installations can benefit from incremental process improvements in aircraft flow, both inflight and on the ground. Even a small improvement in operational efficiency may have a profoundly positive impact.

1. Department of Defense Energy Strategy

The Defense Science Board (DSB) Task Force published a report on Department of Defense (DoD) energy strategy titled *More Fight—Less Fuel* (Under Secretary of Defense [USD], 2008). This report provided an update to energy policies and recommendations from an earlier DSB in 2001 (USD, 2001). Evident in both reports was that little had been done by way of reducing the military's dependence on electrical grids and petroleum resources. Furthermore, the board cited significant challenges remaining to our nation and military forces. Specifically, the department still needed to identify barriers to achieving a reduction in energy demand and how it might leverage commercial best practices to fully realize the benefits (USD, 2008). It is widely known throughout the military that one of most significant threats to national security is energy dependence. Effectively communicating the national objective of energy conservation all the way down the chain of command to the squadron level of operations is vital for any credible reduction in energy resource consumption (Intuitive Research and Technology Corporation [IRTC], 2005).

The DSB (2008) report highlights two principal challenges to achieving a reduction in energy resources demanded. First, "unnecessarily high and growing battle space fuel demand" has placed a greater focus on operational effectiveness than on energy conservation (USD, 2008). Since September 11, 2001, the demand for energy in all facets of military operations has grown exponentially. Second, military installations in the US and abroad are completely dependent on an aging and vulnerable commercial infrastructure for the delivery of fuel and electricity. Given these two significant challenges, the military is placed at an "unacceptably high risk of extended interruption" (USD, 2008).

For more than 10 years, the DoD has made efforts to modify existing business practices and procedures by incorporating energy consequences into everyday decision making (USD, 2008). However, the results are mixed. Decisions today, especially in aviation where success is measured in flying hours as opposed to gallons saved, operational effectiveness carries the day. So long as readiness benchmarks are achieved, fuel reduction considerations are viewed as lost training opportunities. This mindset is not sustainable and represents much of the motivation behind this MBA project's research questions.

In addition to practices and procedures, the DSB uncovered hundreds of mature technologies available for immediate implementation. Unfortunately, the DoD lacks the tools necessary to weigh the operational and economic benefits (USD, 2008). Although Naval Aviation has come a long way since 2008, leadership at the type wing and squadron level today is still not fully evaluated in its ability to conserve fuel. Until energy conservation is tied to a leaders' personal performance (fitness reports), this disconnect will likely remain.

A high-level, energy vision for the DoD suggests changes in operational practices and procedures affecting energy conservation are long overdue. To date, much of this rhetoric has fallen on deaf ears. Strong organizational culture, outdated performance metrics, and incongruence between operational effectiveness and fuel preservation have delayed aviation energy conservation initiatives. This presents a unique gap in research that this study aims to address. Managing the rate at which aircraft arrive to realize efficient ground resource utilization is an area absent in the literature. Specifically, no study addresses how small planning changes at the squadron and type wing level could result in more ready and capable aircrews while simultaneously reducing total fuel consumed.

At the GreenGov Symposium in 2011, Assistant Secretary of Defense Sharon Burke outlined a three-prong approach to reducing operational energy for the warfighter. Her vision provided a roadmap for increased capabilities while simultaneously reducing risk and cost to the force. To do this, she proposed an approach to reduce the DoD's energy demand (*more fight, less fuel*); secure the supply of fuel to our installations (*more options, less risk*); and build a culture of energy security (*more capability, less cost*) (Burke, 2011). The right culture, willpower, and infrastructure to support energy conservation are all necessary to making Naval Aviation a leader in conservation.

The U.S. is the world's leading consumer of oil yet retains less than two percent of the world's oil supply (Energy Information Administration [EIA], 2012). The energy markets have a choke hold on the U.S. and, more specifically, our military. Secretary Burke highlights the strategic implications of failing to respond to the increasing geopolitical and fiscal pressure of energy dependence. China and India make up the largest share of Asian energy growth through 2035 (EIA, 2012). Couple this logistical pressure with a shrinking defense budget, in both real and nominal terms, and changes to current energy policy become paramount. The National Military Strategy states it best, "...forces must become more expeditionary in nature and require a smaller logistical footprint in part by reducing large fuel and energy demands" (DoD, 2011).

The symposium's findings and recommendations provide a relevant vector for Naval Aviation to embrace. Secretary Burke's strategic approach could shape energy policy at the type wing and squadron level. This study fills a necessary gap in knowledge and information exchange to increase aviation readiness while reducing risk to scarce resources under an umbrella of fiscal restraint.

2. Naval Aviation Energy Conservation (Air-ENCON)

The Navy consumes 30 percent of the entire DoD's petroleum budget (DON, 2012). Furthermore, the Navy uses 75 percent of its energy afloat and 25 percent ashore, where this study focuses its effort. The Navy's *Energy Vision for the 21st Century* (2012) is one that values energy as a strategic resource. How this imperative is communicated, implemented, and measured at the squadron level is a noticeable gap in the Navy's strategic vision.

Record oil prices in 2008 forced the entire department to rethink their operational and strategic energy policies. Admiral Roughhead, former Chief of Naval Operations (CNO), stood up Task Force Energy to build energy conservation awareness as well as to develop a repository of energy efficient best practices (DON, 2012). The desired end state is a Navy that fully commits to fostering a culture of energy awareness and decision making cognizant of energy consequences at every level.

To achieve this vision, the Navy relies heavily upon its senior leadership to view energy efficiency as a force multiplier. To that end, Naval Aviation has done a superb job educating its senior leadership, increasing its use of high-fidelity simulators, and moving from a "sortie-based" readiness matrix to one that is "capability-based" (DON, 2012). All of these measures are in line with Naval Aviation Vision 2020. Specifically, the Navy expects the force to "operate, fight, and win more effectively, and more efficiently, making the most of precious resources" (DON, 2012). However, these measures have fallen well short of the Navy's goal of a seven percent weighted reduction in fuel consumption (CNAF, 2010). The importance of energy conservation at the O-6 level (i.e., type wing and CVW) is often overshadowed by operational necessity.

Aviation operational policy and doctrine is quite possibly the most difficult element to implement. Naval Aviation is rich in culture, standardization, and measured risk all of which are largely shaped by aircraft mishaps and personnel loss. As with any strong organizational culture, changes in policy appearing to threaten operational readiness are met with stiff resistance (Kotter & Cohen, 2002). To ensure the Navy's energy vision is achieved, Naval Aviation must capitalize on several key enablers including leadership, technology, policy, and cultural change (DON, 2012). Failure in any one of these areas is counterproductive to achieving the Navy's reduced fuel consumption goals. This study bridges the gap between DON energy strategy and unit-level implementation. Furthermore, the approach proposed in this study is simple, incremental, and requires no financial outlay.

Secretary of the Navy Raymond Mabus established several aggressive energy goals for the Navy to achieve by the year 2020 (DON, 2012). The single largest user of the Navy's fuel resources, Naval Aviation, stands most affected by any energy policy. To that end, they are directed to immediately adopt energy efficient practices, technologies, and operations. Formed in 2009, the Navy Air Energy Conservation (Air-ENCON) Program Integrated Project Team (IPT) facilitates collaboration throughout Naval Aviation by implementing Fleet best practices (CNAF, 2010). The program has enjoyed several successes in the form of performance metrics, incentives for energy reduction, and operational efficiencies as highlighted in the Air-ENCON Charter (CNAF, 2010). Despite these successes, this program highlights a number of research shortfalls requiring further study.

Aviation energy research in organizational behavior, ground and airborne resource optimization, and post-flight refueling policy is lacking. To be successful in achieving a seven percent weighted reduction in aviation gallons of fuel consumed, this study and more is critical (CNAF, 2010). An important tenet of Air-ENCON is that all fuel conserving measures must preserve total flying hours while simultaneously not compromising safety or readiness. Therefore, this project presents a unique opportunity for leadership buy-in to foster a culture of energy conservation that not only improves operational readiness, but is sustainable.

The Air-ENCON strategy combines easily measurable metrics with awards and incentives to promote best practices (CNAF, 2010). Commander, Naval Air Force (N40 Readiness) is interested in this project's analysis and recommendations as it addresses several key gaps in Naval Aviation's energy strategy. Furthermore, this project applies several commercial and military best practices to common aviation operational decisions made every day. Regardless of aviation community (i.e., F/A-18, P-8, H-60, F-35) or air installation, all of the initiatives presented in this report may be applied to achieve operational efficiency and conserve fuel.

3. Incentivized Energy Conservation (i-ENCON)

The Center for Defense Management and Research (CDMR) at the Naval Postgraduate School, Monterey, California (2009) conducted a study of strategic communication as a best practice in energy conservation. Their research concluded the principal factors affecting conservation are personnel attitudes, understanding of energy objectives, motivation, and leadership (Salem, King, Fox, Haley, & Klotzbach, 2009). This study highlights success in the Surface community's implementation of Incentivized Energy Conservation (i-ENCON) and Shipboard Energy Management and Cold Iron Program (SEMPCI). Although the report covers the benefits of these programs at length, the drawbacks the Surface community encountered are of particular interest to our project. Issues such as program awareness, easily understood and controllable metrics, a feedback mechanism, the explicit role of leadership, and persistent cultural and communication barriers are among the many barriers to performance (Salem et al., 2009).

Interviews assessed aircrew perceptions of energy conservation. CDMR's analysis revealed a wide range of safety-related concerns from any measure changing existing operational policy or procedure (e.g., fuel loading, aircraft configuration). Therefore, CDMR recommended a broad-based approach to behavioral change through focused communication efforts in key stakeholders such as type wing commanders, commanding officers, aircrew, and maintenance professionals. After all, the senior leadership is ultimately responsible for setting realistic goals for specific fuel reduction targets. Furthermore, senior leadership is specifically tasked in the Navy Air-ENCON Charter (2010) to take charge of the energy conservation initiative.

Another recommendation is to improve information exchange throughout the chain of command, especially among junior personnel. Conservation awareness is currently not a part of all operational decisions resulting in further delays in achieving the Navy's energy goals. This study found that aviators preferred face-to-face interactions to written policy statements and other media (Salem et al., 2009). Therefore, training, program awareness, and personal responsibility require additional attention to improving communication and expectations.

Ingrained beliefs impact conservation behavior as well (Salem et al., 2009). For many of those interviewed in this study, mission goals and readiness often outweighed conservation goals. A real opportunity exists to align the warfighter's values with that of the Navy's energy objectives. If measured and incentivized correctly, it may be possible to reduce fuel consumption while holding total flying hours per crew constant. To be successful, energy conservation messages must be packaged in a way that aircrew and maintenance professionals clearly understand. Such metrics should include war fighting capability, battle space efficiency, force multiplier achievement, and provide competitive challenge to name a few (Salem et al., 2009).

Most of the aviators interviewed were not motivated to conserve based on efficiencies alone. Conversely, any conservation measure that resulted in improved readiness was seen as an incentive (Salem et al., 2009). If savings in fuel could be partially retained at the unit level, such as the case with i-ENCON's cash awards system, many would consider the efficiency a motivator. Another reason uncovered to entice cultural change is in the form of personal awards and other targeted recognition. This is a critical point that ties directly back to an effective system of performance metrics. For any incentive program to be sustainable, it must be objective, challenging, attainable, and benefit one's own organization in some tangible way (Merchant & Van der Stede, 2012).

The last CDMR recommendation was to leverage existing processes, technologies, and policies through a refocus on conservation. Their analysis highlighted several conservation enablers for aviation including a more efficient use of runways, improved air traffic control systems, and better delay management (Salem et al., 2009). From an administrative policy perspective, some interviewees suggested tying energy conservation to an officer's fitness report.

The Center for Defense Management Research identified several opportunities for further research. This MBA professional report builds on CDMR's findings by providing concrete solutions to many of their key tenets. Effective collaborative tools to define and measure conservation performance can improve strategic communication at the type wing and squadron level. One such initiative could be balancing the flight line by smoothing out variability in departures and arrivals to reduce ground and airborne delays. This balanced approach may lead to improved fuel consumption without impacting readiness.

A second order effect of improving predictability in aircraft arrival rates is in post-flight refueling. A gap in many refueling studies is an assumption that sorties are evenly executed across the fly day. Actually, most flight lines experience predictable patterns of sortie peaks and valleys resulting in the inefficient use of scarce refueling resources. As CDMR eloquently points out, aircrew are far more prone to adopt fuel conserving strategies that do not impact flying hours, readiness, or safety. Balancing the flight line's operations, for example accomplishes all of this and more through incremental scheduling policy changes.

B. CONTEXT

1. Current Naval Aviation Organizational Structure

There are 29 Active and Reserve Naval Air Stations (NAS) and Facilities (NAF) in operation. Each airfield is host to a variety of aircraft types including fixed- and rotary-wing as well as manned and unmanned air vehicles (UAV). At the unit, or organizational level, is the squadron. When squadrons are grouped together, they form type wings (administrative) and carrier air wings (operational) (Figure 1). Squadrons typically have a wide numerical range of aircraft assigned from as few as five to more than 100. Wings, on the other hand, typically have but a few squadrons; often less than 10. Within every squadron is a department dedicated to operations and another to aircraft maintenance. Beyond the squadron and wing is the ground and aviation support organizations of the parent airfield. At this level are the supporting agencies including air traffic controllers (ATC) and managers (ATM), range controllers, ground electronics, fuel services, meteorology, and fire support to name a few.

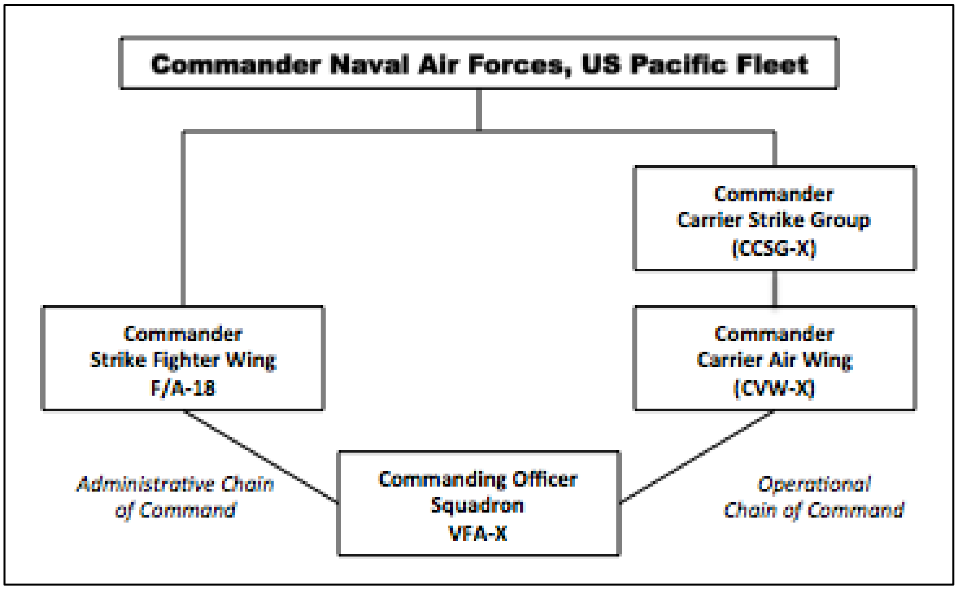

Figure 1. Commander, Naval Air Forces, U.S. Pacific Fleet Organizational Chart

Flight operations are complex and dynamic requiring a variety of talents and experience to ensure aircraft operate in a smooth and efficient manner. Safe and expeditious operations are of utmost importance. To that end, a significant amount of planning, budgeting, executing, and evaluating occurs across the flight line from a variety of stakeholders and perspectives. These stakeholders can be viewed from one of the three organizational levels introduced; squadron, wing, or airfield.

Every military squadron has a mission statement or purpose to justify operations toward a common objective or requirement. Typical operational purposes include combat readiness, cargo and/or personnel transport, and proficiency. Given a host of unique and competing interests within each squadron, the Operations Officer (OpsO) is responsible for ensuring that their squadron is ready and able to provide services when called upon to do so. He does this by orchestrating flight hour demands with maintenance requirements and administrative and safety necessities in the form of a daily flight schedule. The Maintenance Officer (MO) references this schedule in developing the aircraft maintenance plan. Each of these department heads works directly for their respective Commanding Officer (CO) who leads and directs the entire effort (Figure 2).

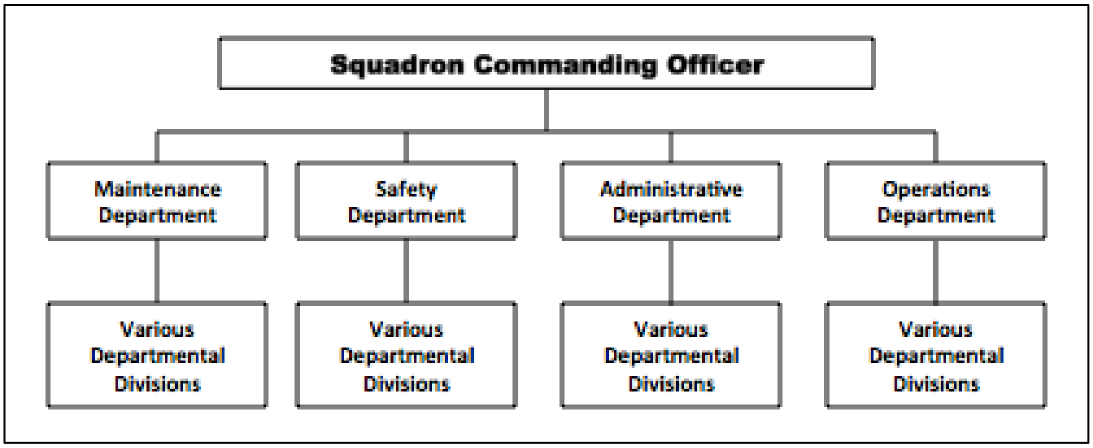

Figure 2. Naval Aviation Squadron Organizational Chart

At the type wing level, one will find the senior, administrative leadership in any airfield complex. Its purpose is to work with all squadrons assigned in matters pertaining to manning, training, and equipping. The wing helps squadrons achieve their operational objectives by providing range and air space control services as well as brokering simulator scheduling and specific air traffic management issues. The wing also makes critical resourcing decisions in order to ensure all squadrons achieve their training and readiness objectives.

Finally, the airfield itself has a number of stakeholders ensuring the runway, control tower, terminal, refueling services and hangars are available and operating in a predictable and efficient manner. ATC monitors ground and flight operations from a demand and capacity perspective and negotiates with the greater National Airspace System (NAS) in the launch and recovery of aircraft. Working closely with their ground operations division, they ensure the runway is free from hazard, the aircraft refueling sources are operational, and navigational aids are calibrated for peak performance. Another principal stakeholder in any airfield operation is that of meteorology. Every decision maker at the squadron, wing, and airfield level is influenced by weather observations and forecasts.

Whether operating fixed or rotary-wing aircraft, the challenges for any Navy airfield is how best to align the behaviors of individual squadrons and wings with the greater objectives and goals required by Commander, Naval Air Forces (CNAF). In the current managerial framework, each individual command lays out their objectives in terms of CNAF established readiness, financial, social, and environmental goals. Each CO in command at the squadron level is personally responsible for managing his own organization in achieving a unique set of operational, maintenance, safety, and administrative metrics. This individual stakeholder approach has merits internal to the organization, but has some significant external drawbacks counter to CNAF's energy strategy.

Squadron performance is measured at the squadron level. All predetermined training and readiness standards are measured first at the squadron level and subsequently aggregated at the wing level. Should corrective action be necessary to address performance shortfalls, all are attributed to a specific squadron. This organizational framework results in management controls at the squadron level (among departments) being highly proactive while controls interfacing with outside stakeholders (e.g., carrier air wing, type wing, airfield manager) being predominately reactive.

There are a variety of results controls in place at the squadron level to ensure personnel within those organizations perform well. Furthermore, personnel at the squadron level are empowered, challenged, and incentivized to take whatever actions deemed necessary to ensure the success of their own organization. The current management control system framework also includes several action, personnel, and cultural controls. As with the results controls, each are orchestrated at the squadron level, with squadron objectives, and squadron strategies to achieve them. Here again, our research suggests that when individuals act in their own self-interest, the impact to the entire aviation enterprise may not necessarily be positive.

2. Current Scheduling Process

The Fleet Readiness Training Plan (FRTP) is a 27-month training cycle that allows CNAF to position fleet squadrons in a set readiness level based upon the current force structure requirements of the Navy. The FRTP is a planning and programming framework tailoring each unit's funding and readiness level incrementally throughout the 27-month period. Each operational squadron is responsible for meeting individual training and readiness metrics based on the number of pilots they currently have on board, and where they are at in the FRTP cycle. Figure 3 depicts a notional funding profile in percentage of total training and readiness as related to the number of flight hours allocated. It is clear that during periods of maintenance and sustainment, the flight hours necessary for training and readiness are least. On the other hand, the greatest demand for flight hours is in the integrated and deployment phase. Figure 4 depicts the same notional funding profile with the percentage of Ready for Tasking (RFT) aircraft required in each month. Here again, each metric shadows the other in each readiness peak and valley.

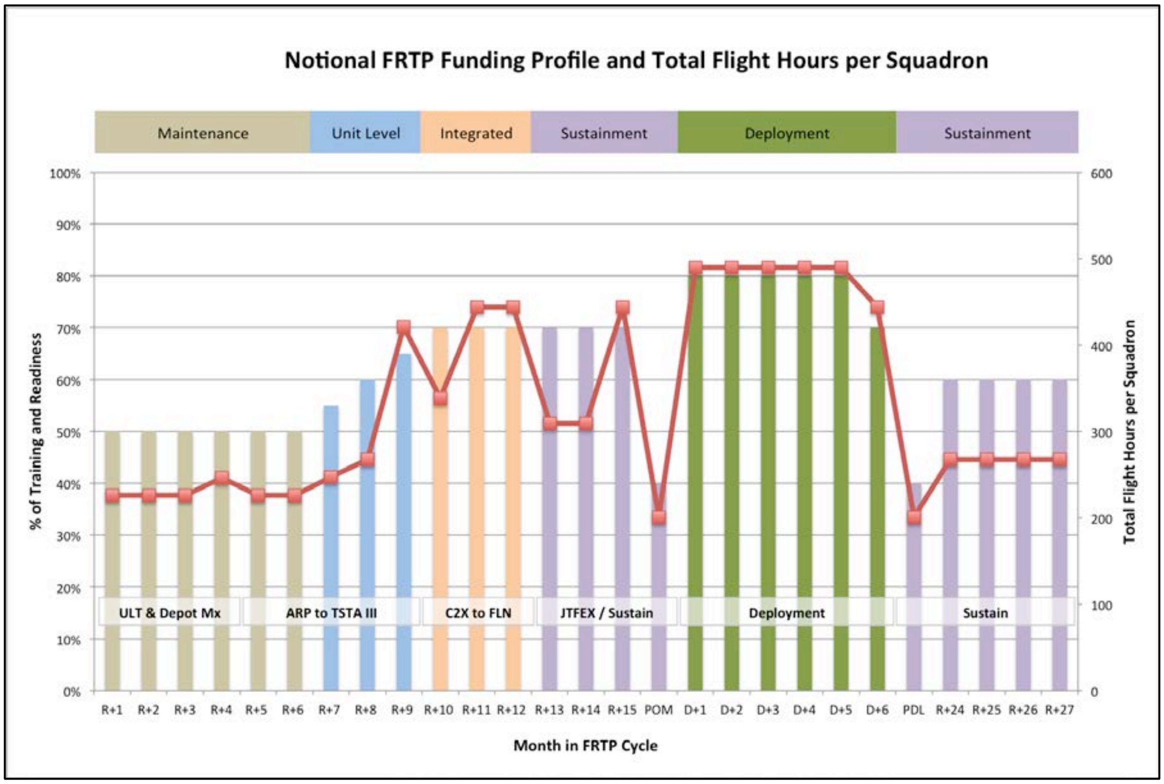

Figure 3. Notional FRTP Funding Profile and Total Flight Hours per Squadron

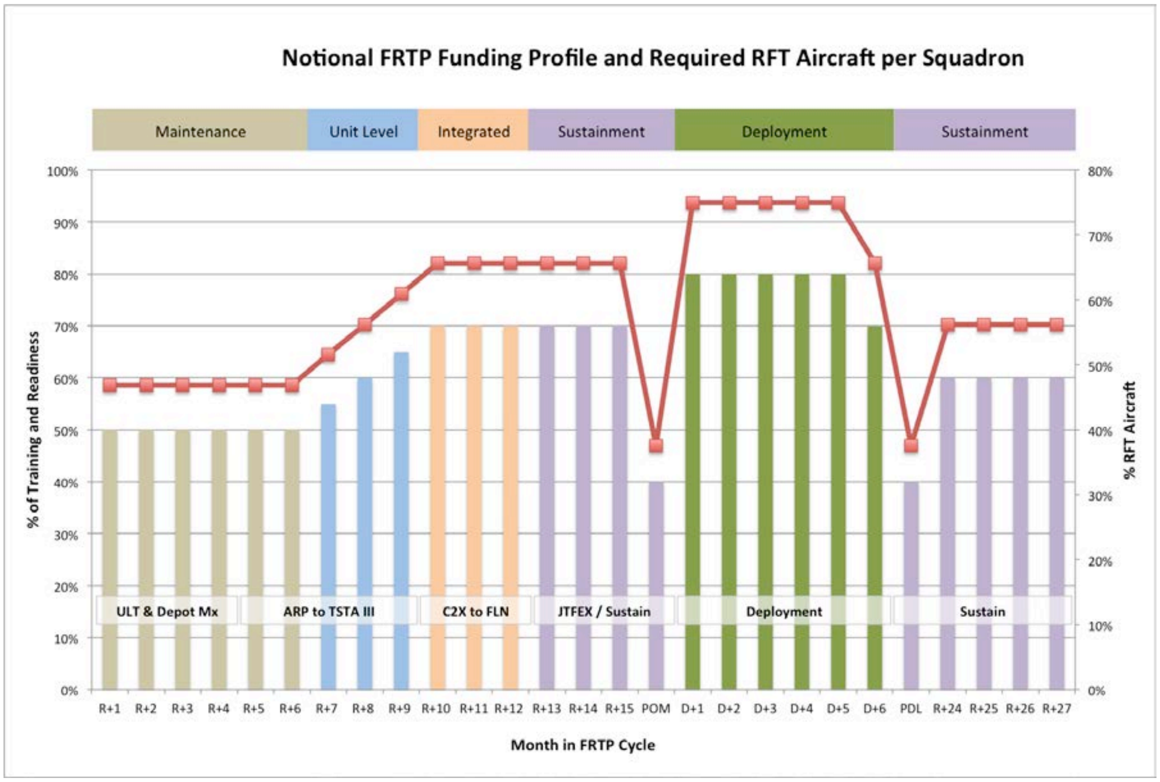

Figure 4. Notional FRTP Funding Profile and Required RFT Aircraft

Naval air installations have certain resources, which are limited for time, availability, manning and cost and are always a source of constant competition for squadrons. These resources include the availability of fuel trucks for cold refueling operations and hot refueling skids, as well as the training ranges located within close proximity of the field. The priority and scheduling for these resources are not currently regulated. In fact, they are scheduled on a first come, first serve basis or, often times, sorted out on an individual basis as needed on the ground or airborne. This leads to a highly variable demand for resources as each squadron operates in their own self-interest.

Under the status quo, each operational squadron and the Fleet Replacement Squadron (FRS) are responsible for their own scheduling requirements. This includes launch and recover times, as well as the ranges and the type of refueling required between each sortie. Each squadron creates a monthly training plan indicating a rough estimate of the required sorties. This monthly planning document is taken and refined on a weekly basis to create a squadron weekly training schedule. This product is used for planning purposes by the other departments within the squadron. Then, due to the complexity and required flexibility of each unit, they refine the weekly plan further into what becomes the signed daily flight schedule upon which each squadron will operate from. These schedules are uniquely formatted for that squadron's needs. The daily flight schedule is disseminated to the various departments within the squadron and base support activities for execution the following day. This is the first time that stakeholders external to the squadron see the operational plan, in many cases this is less than 12 hours prior to the first launch.

Much like the tragedy of the commons, the current scheduling systems do not allow for efficient utilization of limited resources such as refueling assets and training ranges. High demand variability in the current system results in lost training, man-hours, and flight hours. These losses in efficiency lead to critical delays in aircraft operations throughout flight schedule execution.

3. Type Wing Leadership

The U.S. Marine Corps Command and Staff College completed a study in 2009 addressing the U.S. Air Force's rising energy prices, aging aircraft, and stressed defense budgets (Spencer, 2009). The report concluded that wing leaders "are positioned perfectly to establish a new paradigm and promote the cultural shift necessary to reduce the stress on the fleet" (Spencer, 2009). This Air Force study applies in many ways to the research questions answered in this MBA professional report. Naval Aviation is in a similar predicament in that it has invested in high fidelity simulators, reduced their flying hour program to the lowest acceptable level, and maximized maintenance quality assurance at the squadron level. The Air Force's stressed defense spending budget experiences are similar to the Navy's today. Therefore, as the cost to operate rises in the face of economic uncertainty, Naval Aviation leadership is well poised to lead a solution for a more efficient and effective flying force. Furthermore, no one knows the manning, training, and equipping resource requirements better than the type wing commander.

The Spencer study is appropriately titled *The Precious Sortie* (2009). According to the Energy Conservation Charter endorsed by CNAF in 2010, the Navy's objective is not to reduce flying hours, but to reduce the gallons of fuel consumed while executing those flying hours (CNAF, 2010). This project supports the Navy's premise that flight hours should not be reduced further and that simulator usage is likely already maximized. A focus on flight operations, therefore, is the next step in the series of potential energy conservation measures.

Optimizing the "low-hanging fruit" options of reducing flight hours and increasing simulator usage is complete. Consequently, Naval Aviation ought to revisit and evaluate their existing cultural and procedural norms. It is extremely important that every pilot realize that sorties are no longer "cheap" (Spencer, 2009). This will take leadership from the top to accomplish. For example, as the F-35 Lightning II's initial operational capability (IOC) date continues to move into the future, operational pressures fall on legacy aircraft such as F/A-18C/D, EA-6B, and AV-8B, which are aging with considerably higher maintenance costs to keep them available (M. Angelopoulos, personal communication, January 30, 2013). Regardless of aircraft type, type wing commanders should promulgate changes to the administrative portions of every flight with a focus on fuel consumption. After all, the flying hour program (FHP) is about quality and readiness, not quantity (Spencer, 2009). Unfortunately, squadron flight hour execution incentives emphasize quantity over quality.

Defense spending in the future is highly uncertain. Instead of reactively shaping Naval Aviation operations around the amount of resourcing allocated, type wing commanders ought to preemptively focus on efficiencies on their own flight line. A creative and innovative type wing commander can easily address squadron short-term demands and buy time for the delivery of newer aircraft and a more predictable fiscal landscape (Spencer, 2009).

The type wing has the authority, flexibility, and autonomy to have an immediate and positive impact on their flight line. Furthermore, no one is in a better position to lead cultural change on his or her flight line than the wing commander (Spencer, 2009). Through leadership, an incremental change in the behavior of subordinate squadrons results in less timing delays (in-flight and on the ground), less fuel consumed (gallons), and a greater understanding by all (through education). Greater understanding and communication of energy conservation priorities pave the way to cultural change.

C. BENEFITS OF THE STUDY

From the evidence presented in government, commercial, and academic reports in this MBA project, Naval Aviation must evaluate their longstanding business processes. Failure to advance operational policies in the current fiscal environment, as well as align to the aircraft procurement strategy, leads to a senseless waste of scarce resources. Energy management is now an operational and strategic imperative (Myers, 2011).

This project develops a model using advanced simulation software for the purpose of answering the following three research questions:

1. What impact would decreasing variation in aircraft arrival rate per hour have on gallons of fuel consumed during post-flight ground operations?
2. How much time between flight events should squadrons plan for when developing their daily flight schedule?
3. What is the marginal impact in both gallons of fuel consumed and aircraft operating cost from continuing operations in similar fashion as today with an all F/A-18 Super Hornet flight line in 2016?

While a Navy-wide aviation model would provide a good tool for top-level decision makers, a tool focusing on aircraft with the highest fuel burn rate is most efficient. The F/A-18 Hornet and Super Hornet cost an average of $113 (FY12) per minute to operate on the ground during post-flight operations (M. Angelopoulos, personal communication, January 30, 2013). The goal of any policy recommendation from this study is to decrease the amount of time an aircraft spends on the ground without any impact to operational effectiveness, readiness, or safety. All recommendations shall be in the form of gallons of fuel consumed relative to the current baseline of operations.

The F/A-18 is operationally employed across the Naval Aviation Enterprise from 11 different air installations. Although each base is configured differently, applying lessons learned from this report to the other major aviation installations would provide a more comprehensive cost savings estimate. Figure 5 depicts annual flight hours flown in non-operational, land-based, flight operations. EA-18G Growler operations are included due to similarities in ground operations. Land-based flight events excluded from Figure 5 include all flight operations supporting research, test, and evaluation as well as Navy Flight Demonstration Squadron (Blue Angels). In total, the Navy flew nearly 131,000 F/A-18 hours ashore. NAS Lemoore, highlighted in red, represents just 28 percent of the operations captured by this study.

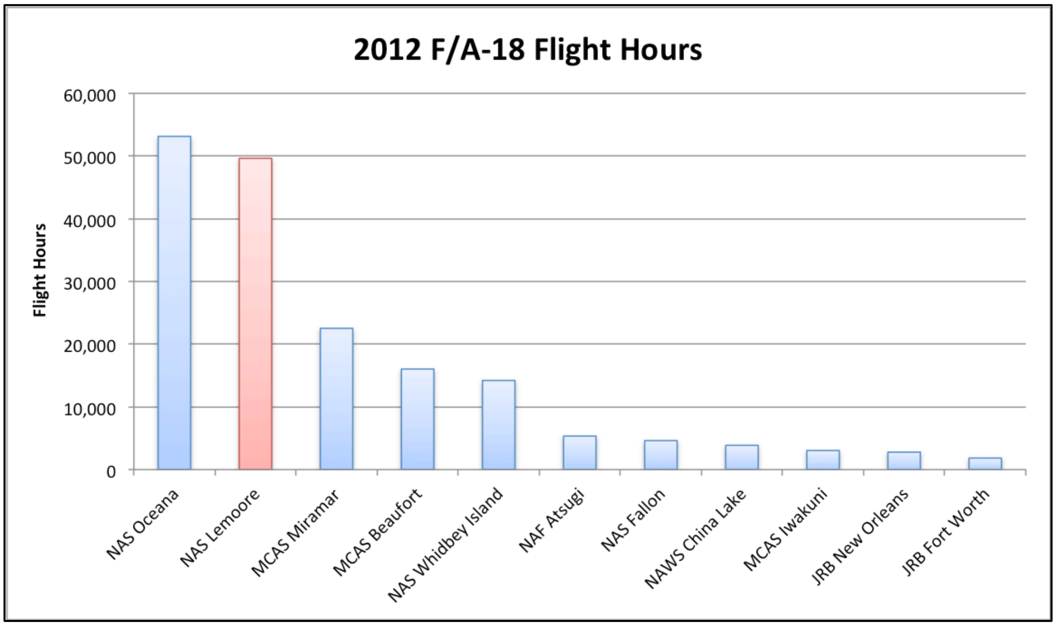

Figure 5. 2012 F/A-18 Flight Hours

The model developed for this project could be modified to answer many questions requested by top-level decision makers. Other fuel conserving opportunities beyond the scope of this study, but worthy of further investigation include the following:

1. Remove all midboard and outboard pylons from F/A-18EF aircraft when operating ashore;
2. Avoid filling external fuel tanks in F/A-18EF aircraft when operating in local airspace ranges ashore to the maximum extent practicable;
3. For routine flight operations, delay engine starts to no earlier than 25 minutes prior to scheduled takeoff;
4. Do not further investigate military power takeoffs in tactical aircraft as a method for fuel savings;
5. Conduct a cost benefit analysis for repairing the Flight-line Electrical Distribution Systems (FLEDS) as a measure to further delay engine start;

6. Research fuel burn and capacity in F-35C Lightning II aircraft and promulgate an appropriate hot refueling policy;
7. Research, develop, and promulgate a dedicated chapter in each aircraft NATOPS Flight Manual addressing energy conservation techniques, practices, and procedures.

D. METHODOLOGY OVERVIEW

Using Naval Air Station Lemoore as the base case, a discrete event simulation model was developed to support each of several experiments. The use of a simulation suite is necessary given the complexity of airfield operations and stochastic elements therein. The model design and implementation effectively simulates aircraft arrival rates, ground operations, fuel trucks, and the impact of aircraft type (F/A-18CD versus F/A-18EF) on gallons of fuel consumed and aircraft operating cost. Furthermore, the stochastic simulation approach utilized in this study models variation, both inherent and network effects, found throughout post-flight ground operations and the impact on both fuel consumption and operating cost.

The dataset supporting the model consists of 21, land-based, fly days from NAS Lemoore during August 2012. In total, there were nearly 2,600 flight events and more than 3,400 refueling events engaged in fuel truck and hot skid refueling. Data from 16 Lemoore-based F/A-18 squadrons adequately represents each of the training phases in the 27-month FRTP cycle. Moreover, NAS Lemoore air wings were returning from deployment, conducting final pre-deployment training, or involved in detachments to other air installations.

Using actual operational flight and cost data, a simulation was developed using the Simio software suite. The model is capable of evaluating numerous policy inputs by quantifying the results in both gallons of fuel consumed and aircraft operating costs (maintenance and fuel). Although flight data was available for the entire operational day, this study focuses its research questions on the period of 0800 to 1759 daily. It is during this period that the application of collaborative decision-making principles would likely yield the best results.

The first series of experiments evaluates aircraft arrivals through slot management techniques. Widely used in the commercial industry, de-peaking arrivals during periods of high demand increases efficiency in ground operations (Ball, Vossen, & Hoffman, 2001). Understanding how cost responds to changes in arrival rate determines how much control top-level decision makers are willing to make to minimize cost. This study provides 12 slot management policy options from which leadership may choose.

On November 23, 2011, Commander, Naval Air Forces issued a mandate for all aircraft refueling to leverage the fuel trucks to the maximum extent practicable (Myers, 2011). The second experiment performed using the model is analysis of four different aircraft ground turnaround policies. At each policy level, the marginal differences in both gallons of fuel consumed and aircraft operating cost are plotted. Using sound statistical analysis of real world data, this study provides the leadership with several policy options from which to choose.

The final experiment assesses the cost of inaction in adopting a slot management policy, a ground turnaround policy, or both. Now through 2016, NAS Lemoore's flight line will transition six F/A-18C squadrons to the newer F/A-18EF as well as receive two new squadrons from NAS Oceana, VA in support of the Navy's "pivot to the Pacific" strategy (J. W. Greenert, personal communication, February 1, 2013).

II. LITERATURE REVIEW

A. AIRFIELD DEMAND MANAGEMENT

Aircraft arrival rates have a critical role in resource allocation in high volume airfields. Some of the principal limiting factors for civilian and military airports are the amount of turnaround time between flight events and aircraft servicing resources. There are a limited number of aircraft and resources available in this equation and finding the correct balance should pave the way toward improved efficiencies and cost savings. Civilian airports experiencing high traffic volume have turned to the process of assigning specific arrival times, or slots to air carriers as a proven technique for reliving the uncertainty of aircraft arrival. Furthermore, implementing slot management leads directly to a more uniform arrival pattern through de-peaking high utilization rates. In turn, by providing a more level demand signal for ground-resources, airports decrease the effects of delay and queues that increase exponentially throughout the day's flight operations.

1. Slot Management and Compression Algorithms

Much research over the past two decades is directed toward increasing airport capacity through the optimization of existing resources. One of the leading research arms of the FAA is the National Center of Excellence for Aviation Operations Research (NEXTOR). NEXTOR is a consortium of eight U.S. universities supporting research on a wide variety of aviation issues. In 2004, Ravi Sankararaman published his University of Maryland NEXTOR thesis on slot exchange systems in air traffic management (ATM). The use of arrival slots during ground delay programs improves resource utilization and fully supports the collaborative decision-making (CDM) philosophy. This thesis in particular discusses the benefits and performance metrics of two slot management mechanisms called compression and slot credit substitution (SCS). The mechanisms differ in that the FAA manages compression slots external to the air carrier, while slot credits are internally managed by the individual airlines (Sankararaman, 2004).

Growth in air traffic demand in the U.S. has led to congestion at many airports. This congestion leads to significant delays and, in 2000, cost the airline industry a record \$6.5 billon (Sankararaman, 2004). Not surprisingly, there are a lot of initiatives underway to improve efficiency by alleviating congestion. One such strategy is through ground delay programs (GDP). When aircraft arrival rates exceed airport capacity, a GDP is initiated by the FAA to limit aircraft demand at that airport. This in turn ensures the capacities of terminals, gates, taxiways, and other ground resources are not exceeded as well. Implementation of GDPs and other CDM program elements benefit not one airline or airport but the entire air transportation network through impacts down-range (Sankararaman, 2004).

Employing collaborative decision tools, airlines communicate real-time cancelled or delayed flight events to the FAA. When enough airlines have reported cancellations or delays, the FAA runs a compression algorithm to move forward other delayed flights. The idea is that when the airlines work together to communicate vacated arrival slots, other airlines can take advantage of the slack capacity. Compressions are problematic for the airlines when the FAA delays the algorithm or chooses not to execute at all (Sankararaman, 2004). When the FAA does not execute a compression, those available slots from cancellations go unused and result in airline costs that could have been avoided. The priority for flights pulled forward are based on their published arrival in the Official Airline Guide (OAG). This ration-by-schedule (RBS) technique results in slots being assigned to airlines as opposed to specific flights (Sankararaman, 2004). This important distinction serves to motivate airlines to report cancellations or delays in a timely manner thereby maintaining their priority in the system.

In the case of slot credit substitution (SCS), instead of a “batch process” completed by the FAA, SCS is orchestrated through individual airline requests. Achieving the same objective of increasing airport utilization, SCS does it in a different way. SCS is fairly new and responds to the growing concern by the airlines that they do not have enough input into the slot management system during GDPs. Furthermore, SCS is considered a conditional request where “an airline is willing to cancel one of its earlier flights only if it is able to get a replacement slot that it desires" (Sankararaman, 2004). It is clear that SCS processes require more collaboration to achieve an optimal solution.

The results of the NEXTOR study revealed airlines using SCS at a greater rate than compression algorithms. This is significant because when the FAA chooses not to compress, the airlines lose the potential benefit. Furtheremore, the incentive to cancel flights is weakened believing the FAA will not make use of the vacated slots in a timely manner. SCS results in a smooth aircraft arrival rate and subsequent ground traffic flow. Although the onus for slot substitution is brokered by individual airlines, the flexibility they enjoy greatly outweighs the administrative burden (Sankararaman, 2004).

The concepts highlighted in the NEXTOR study could be adapted to demand management solutions for Naval Aviation. This MBA project has a goal of improving refueling truck utilization, at the expense of hot pit refueling, by balancing demand for fuel resources. As variation in aircraft arrivals (demand) is reduced, so too is the demand for fuel trucks. This reduces the potential for long delays in aircraft refueling thus ensuring follow-on flights proceed as scheduled. Bottom-line, increased collaboration between squadrons for slot arrival times may yield improved benefits for all stakeholders involved.

2. Managing Aircraft Arrival Uncertainty

In 2001, Michael Ball, Thomas Vossen, and Robert Hoffman conducted a NEXTOR demand analysis project at the University of Maryland. Their report investigated the impact of CDM on aircraft arrival time uncertainty during GDP and the consequences of performance. Although the concepts and definitions support the commercial transportation industry, the analysis and recommendations proposed are directly applicable to a host of defense applications, including the implementation of an aircraft arrival slot management system at naval air installations.

Two models were introduced in this report including a stochastic integer programming (IP) and a simulation model (Ball et al., 2001). In both applications, actual historical flight data was utilized. Using these models, the researchers were able to simulate the impacts of CDM on the implementation of GDPs. The purpose of a GDP is to align aircraft arrival demand with airport capacity. For example, if reduced weather visibility at a destination airport is preventing aircraft from landing, that airfield's capacity is necessarily reduced. A GDP, therefore, may be initiated by air traffic control, under the oversight of the FAA, as a temporary demand management measure. Essentially, GDPs hold aircraft on the ground at the originating airport until the destination airport has the capacity, or capability, to safely recover the aircraft.

There were three focus areas identified in the study (Ball et al., 2001). The first uses a simulation model to show how uncertainty of demand affects airborne arrival queues that, in turn, affect airport utilization rates. The authors showed how destination airports could increase their aircraft arrival rates if unexpected cancellations were known ahead of time (Ball et al., 2001). One of the key tenets of CDM is improved communication and information exchange not only between the airfield and air traffic control, but among the airlines as well. Furthermore, decentralized decision making speeds up communication and ensures the impact of delays and cancellations are minimized. Knowledge of cancellations frees up resources in secondary and tertiary service sectors thus further improving GDPs (Ball et al., 2001). To prove this assertion through simulation, the authors depicted the destination airfield as a single-server queuing system. When a GDP is in effect, arriving aircraft are assigned a unique sequence number, or slot time. When cancellations are not communicated, unexpected gaps, or unused slots, result in inefficiencies at the destination. This simulation showed how timely flight cancellation notifications improved aircraft arrival rates at destination airfields (Ball et al., 2001).

The second focus area uses a stochastic IP model to calculate the best aircraft arrival rates in the face of demand uncertainty. The report focuses on three main sources for demand uncertainty and the marginal effect on GDP performance, including unexpected arrivals ("pop-ups"), aircraft arrival time ("drift"), and cancellations (Ball et al., 2001). Each of these sources changes the number of aircraft expected at the destination airport. As changes in destination airport utilization occur, GDP performance is weakened from lack of accurate aircraft arrival information. Pop-ups are easily understood as general aviation aircraft, military aircraft, and add-on flights by airlines.

Pop-ups are problematic because they are not in the Official Airline Guide (OAG) at the start of flight operations. Drift, on the other hand, is typically caused by enroute congestion and late departures from originating airports. The results of their analysis showed that limiting unknown cancellations to less than 15 percent; ensuring pop-up rates are less than 10 per hour; and holding arrival time slot error to less than 10 minutes will go a long way toward improving effectiveness in ground delay programs (Ball et al., 2001).

The last focus area in this report showed how timely cancellation notices reduce the uncertainty of flight arrival time. The result of their analysis showed that drift, time variance in planned arrival had the greatest impact on airborne delay time (Ball et al., 2001). As variance in arrival time increased, so too were adverse impacts on GDP. For this reason, the authors proved that when airborne aircraft were very early or late from their assigned slot time, the impact was likely uneconomical for all involved as an aircraft is forced to remain airborne until it can be sequenced in for landing (Ball et al., 2001). Other demand uncertainty unknowns, namely pop-ups and add-ons, further compound the effect of drift on airborne delay.

This MBA project uses the NEXTOR study as motivation for the implementation of an arrival slot management system at naval air installations. Loosely applying the article's GDP concepts to post-flight refueling resourcing may reduce ground delays, increase fuel truck utilization, and decrease aircraft turnaround time. All of these benefits reduce manpower cost, gallons of fuel consumed, and aircraft operating costs overall.

3. De-peaking through Slot Management

Massachusetts Institute of Technology (MIT) conducted highly relevant demand management research as a temporary means of relieving airport congestion (Fan & Odoni, 2001). Prior to the terrorist attacks on September 11, 2001, the National Airspace System was experiencing rapid growth in traffic volume amid a highly static airport operating environment. With demand exceeding the capacities of many U.S. airports, much research was, and still is, necessary to keep flight delays under control (Fan & Odoni, 2001). Leading into this project, a significant gap in research was quantifying the impact that managing aircraft demand can yield. The analysis presented here contrasted three airports of varying demand levels to assess the impact of managing demand.

The authors chose three airports to represent the two capacity extremes, high and low, as well as an airport with increasing capacity concerns (Fan & Odoni, 2001). Over the past 40 years, U.S. airports have used arrival slot management systems to control capacity at the busiest airports. Additionally, almost every major European airport limits arrivals to those aircraft holding slots (Fan & Odoni, 2001). Therefore, in answering MIT's primary research question, demand can be managed by simply shifting aircraft from periods of high demand to low (de-peaking). The author's found that, in the near term, well-designed demand management systems can be far more effective than many other alternatives at controlling congestion for scarce resources (Fan & Odoni, 2001).

The MIT queuing model used data from the OAG, or commercial airline flight schedule, to represent demand. On the supply side, runway capacity limits as published with the FAA were captured in the model. Analysis performed on the model's outputs revealed that very small changes in runway capacity had a significant impact on airport congestion (Fan & Odoni, 2001). The model showed an 80 percent reduction in total aircraft-hours whenever the slot management system was in use (Fan & Odoni, 2001).

Another option presented by the authors for managing airport capacity was by leveling demand peaks through time-of-day shifting. The model implemented a use case by level loading flight operations across the entire day without variance (Fan & Odoni, 2001). Although an extreme situation, the authors were attempting to show the significance of managing demand peaks. The results showed total aircraft delays were reduced 40 percent further during peak periods (Fan & Odoni, 2001). Therefore, it is clear that a combination of managing both arrival time and level loading demand results had the most significant impact increasing airport efficiency.

Where the MIT study precisely managed runway resources through slot management and de-peaking, this MBA project applies the same two-fold combination to the demand for refueling resources. Fan and Odoni made clear that merely implementing a slot management system without level loading total demand would not be particularly effective (2001). This project will simulate the combined effects of fuel consumption on the ground by implementing a slot management system and de-peaking aircraft arrivals across the period in the fly day having the greatest demand variation.

4. Delay Propagation

Many decisions require cost data to truly understand outcome magnitude and risk. After years of data collection and analysis, Andrew Cook, Graham Tanner, and Stephen Anderson published their findings in support of the Performance Review Unit at Eurocontrol in Brussels, Belgium (2004). The authors conducted the study while attending the University of Westminster in London with the objective of quantifying the true cost of aircraft delays both airborne and on the ground. Most cost benefit analysts focus purely on aircraft operating costs, such as fuel, when determining the cost per minute of flight and ground operations (Cook, Tanner, & Anderson, 2004). This study expands the discussion to include direct and indirect operating costs such as maintenance parts support, airport facilities and infrastructure, air traffic control services, crew salaries, and fixed staff costs.

Data in support of the researchers' analysis came from 12 airports operating 12 different aircraft types. Delay costs were captured from day to day operations and subsequently broken down into their fixed and variable components to ultimately determine the true direct and indirect operating cost (Cook et al., 2004). Not surprisingly, the cost to operating an aircraft airborne was significantly greater than on the ground. Furthermore, as delay increases in magnitude, so too does total cost to the airlines (Cook et al., 2004). Another lesson learned in their findings was the impact of delay predictability on the bottom-line. Specifically, the lack of information regarding a particular delay and the anticipated length of it is the primary cause of financial losses suffered (Cook et al., 2004). When the length of a delay is known, subsequent flight events can be adjusted to compensate and minimize its impact. The final conclusion of the study was with respect to delay propagation. Flight operations form a network of arrivals and departures and, therefore, a delay in any one "leg" has a cascading effect until the end of the same operational day (Cook et al., 2004). This “reactionary” or propagating effect was captured in the authors’ research filling a significant gap in the current literature.

Minimizing variability in the length of known delays and monitoring the reactionary impacts of delays are two techniques to further reduce operating costs to the airlines (Cook et al., 2004). The first component could be satisfied with increased communication through collaborative decision-making (CDM). Although delay timing will likely be refined over time, premature information is proven to be better than no information at all. The second component, delay propagation, should motivate earlier flight events to perform precisely as scheduled. The longer the daily fly window is, the longer a delay on the first flight of the day has to impact total aircraft operations. The simulation developed to support this project must also capture both types of delay, inherent and network effects.

Specific direct and indirect costs to F/A-18 operations were captured in the NAS Lemoore study (Hicks, Santos, Cook, & Lassen, 2004). This MBA project developed an airport simulation to explore the impacts of various demand, delay, and queuing characteristics. Knowledge of delay propagation coupled with explicit costing data is a recognized gap in the literature being advanced by our project.

The rising costs of airport operations have increased awareness to energy conservation initiatives and an appreciation for managing unnecessary delays in ground operations. In 2009, Vikrant Vaze of MIT evaluated airport delays and the effects on demand using a stochastic model. The model simulated the effects of multiple variables including weather, traffic volume, equipment readiness, and runway closure (Vaze, 2009). Taken one step further, this model was robust enough to show the impact of each variable on delays in the greater National Airspace System. The ability to hold one or more variables constant while changing another offered great insights into those attributes having the greatest impact on managing delays and demand for scarce resources.

The MIT study examined the dynamic aspects of delay queuing from a cost perspective of marginal changes in demand (Vaze, 2009). He found the addition of a single user on the margins could not be evaluated independently. Given the complexity of airport operations, incremental costs by any one stakeholder has a cascading cost impact on the rest of the system. Although delays are typical of airfields experiencing demand in excess of capacity, this is not always the case. For example, most military airfields operate well below capacity thresholds but experience delays at the hold short for takeoff, delays in flight sequencing in for landing, and delays for cold truck and hot pit refueling. Vaze revealed the same problem in his analysis as well (2009). Operational delays from high variability in demand for ground services such as refueling impacted the daily flight schedule (Vaze, 2009). Perhaps the most significant conclusion by the MIT study was how small reductions in demand variability during critical times yield exponential reductions in aggregate aircraft delay.

Naval Aviation can benefit from the analysis and conclusions in the Vaze article (2009). It appears that incremental changes in the management of military flight operations could yield significant cost savings through delay reduction. An area this MBA project aims to improve over the MIT study is with respect to incentivizing ground resource allocation. Specifically, squadrons on the flight line must be willing to give up a small amount of control over their flight schedule to receive the benefits of better access to airspace, increased readiness, and reduced aircraft turnaround time between flight events.

B. COLLABORATIVE DECISION-MAKING (CDM)

Naval air installations have many ground operations decision makers. These range from air traffic control to squadron operations and from fuel services division to meteorology. Each stakeholder plays a vital role in the safe and expeditious of flow aircraft into and out of the airport. However, our research shows that these stakeholders do not share a common understanding of current operations and therefore make decisions unaware of their impact to other parts of the airfield. It is from this backdrop that collaborative decision-making (CDM) was first brought to light in the early 1990s.

The flow of information throughout an organization is necessary for improving aircraft traffic flow. In this section, we highlight several studies showing the positive impact that CDM can have on fiscal and operational performance as well as the cultural challenges preventing their implementation. When representatives from the squadron, wing, and airfield join together to collaborate, share in mutual understanding, and define their unique problems and opportunities, the entire operation stands to benefit. Although the Navy's current cadre of decision makers are extremely talented, the sheer volume and timeliness of such judgments may very well require the assistance of an automated system to reach their full potential.

1. Traffic Flow Management

In 2007, the National Center of Excellence for Aviation Operations Research (NEXTOR) released a report highlighting traffic flow management (TFM) delay costs of $31.2 billion per year in fuel, crew, and other costs (Ball et al., 2010). Over 15 years earlier, Andrew Lacher and Gary Klein (1993) of the MITRE Corporation conducted a study of the U.S. airline industry and their application of CDM with the FAA. Both of these studies highlight the amount of time required to effect cultural change and the total cost to the airline industry for failing to operate efficiently. Although 20 years have passed in the commercial sector since the Larcher and Klein study was first assembled, many of the same issues they highlighted are commonplace in today's military operational environment.

TFM is the process by which the FAA balances capacity and demand for National Airspace System (NAS) resources, including traffic routes and military ranges (Lacher & Klein, 1993). This study revealed the FAA was making decisions in support of the air carriers with very little information available (Lacher & Klein, 1993). Improved communication, collaboration, and coordination are critical among stakeholders in achieving reduced congestion from delays, improved NAS resource utilization, and reduced overall fuel consumption (Lacher & Klein, 1993).

MITRE Corporation collected data from seven airports of varying capacities with emphasis on air carrier operational decision-making (Lacher & Klein, 1993). A thorough understanding of each airfield's operations was accomplished through observations, interviews, flight schedule analysis, and operational analysis. Although the level of operations varied in each of the seven airfields, several collaboration problems were consistently noted (Lacher & Klein, 1993).

Throughout daily flight operations, changes occur in physical and operational limits, weather, aircraft separation criteria, arrival sector configurations, and controller proficiency. The dynamic operating environment was further complicated by the amount of arriving air traffic and real-time flight cancellations, delays, and add-ons by air carriers (Lacher & Klein, 1993). The only operational element that appeared constant in the study was change itself. Continuous change inherent in flight operations affected all stakeholders simultaneously yet, without a collaborative decision-making tool, left many to make critical decisions on their own with little regard to the other airline and airport managers.

In a TFM decision-making environment, most decisions must be made in a timely manner. Often, decisions delayed just one minute can have a devastating effect. Furthermore, since operational information necessary to make many decisions is dynamic, decisions must be made after monitoring trends over time (Lacher & Klein, 1993). Weather changes, runway and taxi configuration changes, airfield emergencies, and other variables are difficult to forecast accurately. Therefore, the MITRE Corporation recommends a CDM decision support system be implemented to share data between the air carriers and the FAA in near real-time (Lacher & Klein, 1993).

The TFM analysis in this study stops short of developing a stochastic model to simulate the operational environment and quantify improvement opportunities. This shortfall represents a research gap that this MBA professional report aims to fill. The gross lack of communication and collaboration between air carriers, air traffic controllers, and ground resource providers is well documented in the study.

Larcher and Klein's (1993) research found the following:

> It seems clear that whatever specific operational concept is implemented for TFM, a major improvement is needed in the match between the scope of decisions and the granularity of available information. This

> improvement is more one of policy and procedure than of technology. Communication, coordination, and collaboration technologies merely provide a means for implementing more effective organizational policies and procedures; implementation of new technologies without the associated organizational changes historically has not been shown to improve efficiency.

Applying the recommendations outlined in the MITRE Corporation study to naval air installations is a best commercial practice that makes operational sense in land-based military operations. To help illustrate, allow air carriers to represent squadrons and the FAA/NAS to represent base operations. Changing the terms and applying them to the discussion above should reveal how MITRE's arguments hold true today in Naval Aviation.

The lack of communication and collaboration among squadrons, air traffic controllers, base operations, and fuel service providers is well known. This MBA report explores the impact CDM policies and procedures have on aircraft delays and fuel consumption.

2. Aviation Decision Support Systems

An expert in the field of aviation decision support systems, Professor Kostantinos G. Zografos of Athens University, revealed SPADE DSS to the European Commission in 2010. Supporting Platform for Airport Decision-Making and Efficiency (SPADE) provides, for the first time, a decision support tool integrating both flight and ground operations offering solution recommendations complete with resource trade-off information (Zografos, Madas, & Salouras, 2010). Until SPADE, several attempts were made to capture frequently asked questions and decisions made by aviation managers. In each case, robust modeling and simulation of a particular subset of an airport's total operation was completed. SPADE, however, addressed the interdependencies of several airport and airspace systems as well as the trade-offs necessary to ensure the best total airport performance (Zografos et al., 2010). The principal U.S. airport modeling software suites were developed by MITRE Corporation, Preston Aviation Solutions (Boeing Company), and International Air Transport Association (IATA). These joint government and commercial air operations management suites are fast, accurate, and offer many of same tools as SPADE. However, the U.S. systems are not very adaptable, they are difficult to install, and are difficult for end users to interpret the results (Zografos et al., 2010). For these reasons, the European SPADE provides a well-integrated decision support solution to fill these modeling gaps and capabilities.

The SPADE software suite addresses the efficiency of the entire airport complex while simultaneously evaluating the interdependencies between flight and ground operations. This MBA project benefits from the motivation and underlying framework of SPADE. Specifically, understanding how detailed, tactical decisions impact the larger, strategic airport operation is vital to improving efficiency and effectiveness overall. Every decision made by an airport or air carrier stakeholder results in trade-offs. These trade-offs could be time, money, performance, or any combination of the three (Zografos et al., 2010). Furthermore, the consequences of one decision may have both positive and negative impacts on one or more related processes. The SPADE framework first captures supply-side metrics including runways, taxiways, apron (ramp) areas, and flow facilities (ground resources) (Zografos et al., 2010). The second framework layer applies CDM to supply-side constraints in an attempt to optimize their ability to meet or exceed the air traffic demand signal. Changes in the final layer, traffic volume (demand-side), from flight modifications, cancellations, and additions impact the supply of resources. These impacts manifest in trade-offs such as reduced ground resource levels, delay queues, capacity limitations, and safety concerns (Zografos et al., 2010).

Given the predictable nature of individual stakeholder decision-making inputs and processes, SPADE successfully developed "use cases" to package the operating environment (Zografos et al., 2010). These encapsulated tools enabled an integrated approach to measuring airport effectiveness and their associated trade-offs. In similar fashion, this MBA project brings together observed supply- and demand-side constraints in a simulation to analyze post-flight ground operations. Focusing on SPADE's third framework layer, our project introduces a variety of potential policy recommendations to the simulation to reform the imbalance between supply and demand. Ensuring a predicable demand signal for airport and ground resources may yield a significant improvement in total air efficiency and effectiveness at military airfields.

3. United Airlines DSS Case Study

The dynamic nature of flight operations and complexity of resourcing decisions is highly evident in the commercial airline industry. United Airlines, for example, implemented the System Operations Advisor (SOA) system in 1992. Although this system is 20 years old, the fiscal and administrative benefits are highly relevant today and even more so for a naval airfield that has never adopted such a system. This system helps decision makers promulgate delay management solutions in near real-time to minimize total cost. During a six-month beta test, UAL saved 27,000 delay minutes amounting to more than $900,000 (FY12) (Rakshit, Krishnamurthy, & Yu, 1992).

United Airlines (UAL) is a good example from which to draw lessons learned for Naval Aviation. First, UAL is a diverse airline operating seven different types of aircraft. Second, in 1992, UAL operated more than 2,000 flights daily. Lastly, UAL launches and recovers at a wide variety of airports both domestically and internationally. The Navy has more aircraft types and twice the number of daily sorties lending further credence to the potential savings from sound operational decisions.

UAL's SOA decision support system increased effectiveness by applying linear programming logic to a dynamic set of flight data in real-time. These continuously computed, objective function, solutions ensure decisions are efficient from a total system perspective (Rakshit et al., 1992). Additionally, many operational decisions are made and disseminated on very short timelines. When decisions in this environment are made late, or not at all, the result can be profoundly negative on the bottom-line. SOA arms stakeholders with information "to make decisions on manpower allocation, cancellations, delays, pilot and flight attendant staffing, as well as flight planning and dispatch to reduce deviation from the schedule and operation plans prepared in advance" (Rakshit et al., 1992).

There are five principal stakeholders involved in United's system, including meteorology, flight dispatch, flight crew management, inflight crew management, and system operations control. This MBA project proposes a similar subset of five stakeholders including meteorology, base operations (air traffic control and fuels division), squadron operations, squadron maintenance control, and type wing operations. Although many more users within UAL's operational hierarchy have access to SOA, only the five principal functional teams are authorized to take action on the solutions recommended.

In a world of infinite resources, the airlines would have an unlimited number of spare aircraft to fill forward when problems with the flight schedule arises. However, not only is it cost prohibitive to operate such a large fleet of aircraft but having them prepositioned at the right airport, at the right time, is unrealistic. Furthermore, because of time constraints, stakeholders are under enormous stress to make the correct operational decision. Mangers simply do not have the time to determine the most optimal cost solution for the airline with respect to flight cancellations or delays (Rakshit et al., 1992). Couple this challenge with as many as 15 such decisions simultaneously and the need for an automated decision support system is required.

Prior to SOA, and in the current Naval Aviation operational environment, many stakeholders delay flights or forgo non-essential aircraft maintenance in an effort to meet the demands of the preplanned schedule. The highest aircraft readiness rates are seen at the beginning of the day. Then, as aircraft problems from weather and maintenance occur throughout the day, delays grow exponentially costing increasingly amounts of time, money, and resources. The Navy continues to struggle from the same problems today making UAL's SOA solution still relevant. Knowing when to cancel or delay a particular sortie and what the impact of such a tactical change has on the greater operational environment (e.g., taxiways, post-flight refueling systems, operational ranges, and National Airspace System) is lost by many stakeholders (Rakshit et al., 1992).

C. AVIATION ENERGY CONSERVATION RESEARCH

Efforts to control rising energy costs through operational efficiencies and reduced fuel consumption are common Naval Aviation objectives. Several quantitative and qualitative studies over the past decade provide valuable insights into aircraft post-flight operations. However, in each case, there is a recommendation for further study to address aircraft arrival rates on the demand side. Understanding the fully burdened cost of fuel truck and hot skid refueling processes as well as the optimal ratio between the two is important, but fall short of the true reason behind ground operation inefficiencies. This MBA project leverages all three of the following studies by taking them to the next level of understanding through an analysis of aircraft arrival variance.

1. Cost-Benefit Analysis of F/A-18 Refueling Operations

All organizations must manage resource limitations in material, manpower, time and technology. Referred to as capacity management, this literature review section considers a Naval Postgraduate School (NPS) cost-benefit analysis attempting to remove bottlenecks in refueling resources to reduce fuel expenditures (Hicks et al., 2004). Although data was compiled from observations at a single naval air installation, the lessons learned provide a solid foundation from which to base this MBA project.

A CNO directive for operational commands to find cost savings in all facets of their operations is what prompted the study (Hicks et al., 2004). Hicks and his team analyzed the two principal methods to refuel an aircraft, cold (trucks) refueling or hot pit refueling. The principal difference between the two refueling procedures is with respect to the aircraft's engines. When truck refueling, the engines are off-line and, when hot pit refueling, the engines are on-line. The research team compared these two refueling methodologies on the basis of cost and determined that it was much cheaper from an enterprise perspective to refuel using trucks than with hot pits. This study resulted in the lease of several additional fuel trucks for this naval air installation in an effort to reduce the demand for hot pit refueling resources.

From a capacity management perspective, this cost-benefit analysis highlights the demand for fuel greatly exceeded the base's truck refueling capacity. The authors discuss a host of limitations and cost drivers to include time, manpower (active duty and civilian), refueling truck contracts, and aircraft component wear and tear (avionics and engine) (Hicks et al., 2004). When demand exceeds capacity, queues develop leading to further waste in these scarce resources (Fan & Odoni, 2001). Losses in equipment, manpower, and time directly impact the operating budget, which could better be applied airborne in the form of additional training and proficiency.

This study was successful in that it led to the purchase of additional refueling trucks. The additional refueling trucks reduced the usage dependence on hot refueling resources thereby reducing cost, unnecessary wear and tear on aircraft components, and led to increased preventative maintenance opportunities as no maintenance can be performed with the engines online (Hicks et al., 2004). Although cost reduction was a key objective in the CNO's directive, this research falls short in addressing variability in the demand for fuel resources. For example, doubling the number of refueling trucks may increase capacity, but this is arbitrary in an environment where demand cannot be accurately predicted. This MBA project attempts to fill this gap in research by building on the Hick's study through an evaluation of the benefits of smoothing out fuel demand.

Any policy or recommendation must be adaptable to meeting the demands of a rapidly changing flight line. Many aviation communities in the Navy are in transition from older (legacy) aircraft to modern airframes. Furthermore, these modern airframes have significantly larger internal fuel capacities than the fuel required of aircraft in the Hicks study (CNO, 2011a, 2012a; Hicks, 2004). For example, in 2004, Hicks based his conclusions from the perspective of Naval Air Station Lemoore. At that time, the airfield operated primarily F/A-18C/D Hornet aircraft. By 2016, however, the airfield will exclusively operate the newer F/A-18E/F Super Hornet with a significantly larger fuel capacity (CNO, 2011a, 2012a). Increased aircraft fuel capacity not only requires more fuel, but more time to refuel post-flight. The decision to refuel an F/A-18E today using the hot pits requires much greater scrutiny than the study's F/A-18C years ago. Other emerging examples include the internal fuel capacities of F-35B Lightning II being 44 percent larger than the AV-8B Harrier II and F-35C being 42 percent larger than F/A-18C (CNO, 2011b, 2013).

2. Improving Refueling Operations Ashore

Augmenting the 2004 NAS Lemoore study, Matthew Geiser of NPS addressed a critical gap in research related to ground refueling (2012). In this follow-on study, the author approached the fuel demand problem through improvements in coordination, dispatch, and communication (Geiser, 2012). He focused on the appropriate communication flow between ground refueling truck operators and the squadron maintenance personnel calling for services. Furthermore, this thesis explored ways to better anticipate the demand for aircraft fuel, minimize the number of truck refills between aircraft servicing, and thus decrease total refueling time (Geiser, 2012).

Geiser found similar results to the Hicks study in that improved communication and collaboration alone did not provide the most efficient solution (2012). Each study showed significant improvement, but both failed to address the underlying problem in balancing the fuel demand signal. Geiser concluded that aircraft typically launched and recovered in clusters (2012). These clusters created periods of demand peaks and valleys throughout the day. These large fluctuations were further complicated by flight additions, cancellations, and modifications. Therefore, policy and procedure recommendations are necessary to smooth out these peaks and valleys (Geiser, 2012). A smooth demand signal for post-flight refueling resources will likely reduce the number of trucks necessary to have on hand, reduce existing wait times to be refueled, and greatly enhance efficiency across the flight line (Geiser, 2012). This MBA project builds upon Geiser's study by evaluating the benefits of level loading aircraft demand through implementing an aircraft arrival slot management system.

Airfield capacity management problems are not unique to Naval Aviation within the DoD. The Air Force has also analyzed the flow of aircraft into, and out of, its airfields. Heath Rushing wrote his thesis at the Air Force Institute of Technology addressing the effects of ground refueling capacity on airfield throughput (1997). His analysis utilized a Markovian decision process to examine aircraft throughput in refueling operations (Rushing, 1997). The models used in the study enabled the user to input a variety of variables affecting ground-refueling operations with a goal of balancing demand within capacity constraints (Rushing, 1997). Furthermore, each model was programmed to minimize the average time each aircraft spends in the refueling system.

The research deliverable was a series of linear programming models for operational planners to use in setting refueling policy to minimize wait queues and increase throughput (Rushing, 1997). According to the study, setting an appropriate refueling policy for the resources available is critical. He suggests that refueling policy could be enhanced through an analysis of aircraft arrival rates and departure processes at each airfield (Rushing, 1997). This study provides a solid basis for our MBA project. Several of the literature review articles covered herein offer tools to help decision makers manage refueling operations. However, each falls short of addressing the underlying problem of balancing the demand-side of the equation. This MBA project builds on the Rushing thesis by quantifying the impact of smoothing out the demand for post-flight refueling resources.

3. Cold Truck and Hot Pit Refueling: Ratio Analysis

The Navy contracted a commercial strategy and technology firm in 2012 to analyze ground-refueling operations at NAS Oceana. Building on the Hicks study of 2004, Booz, Allen, and Hamilton (BAH) identified the optimal ratio between truck and hot pit refueling (2012). BAH concluded by recommending the optimal number of trucks, minimal fuel truck capacity, and further increases in operational efficiency (2012).

This study provides expert insight into the management of refueling resources, but, again, fails to address the root cause of demand variability. BAH contends that balancing the demand for fuel would significantly reduce cost and improve efficiency as a recommendation for further study (2012). BAH did, however, maximize the use of existing infrastructure at NAS Oceana through refueling policy. Although improvements were substantiated, more could be accomplished by way of reduced cost, reduced delay, and improved efficiency if the demand signal was balanced. Maximizing the use of ground refueling resources is not an issue of efficiency as much as it is about managing demand to accurately use scarce resources.

D. ADDITIONAL READING

Appendix B is included at the end of this MBA project for those readers desiring additional CDM information. We have included five successful applications of collaborative decision support systems as well as an introduction to working through many of the challenges associated with cultural change. Although these articles are not critical to understanding the objectives of our project, each provide a foundation upon which a potential solution may lay. It is likely that a non-material solution to managing aircraft arrival variance resides in leveraging existing government systems such as SHARP (Sierra Hotel Aviation Readiness Program) and ISIS (Integrated Shipboard Information System).

III. METHODOLOGY

A discrete event simulation model of Naval Air Station Lemoore was designed and implemented to support an extensive series of experiments. A simulation is necessary given the complexity of airfield operations, non-linear relationships, stochastic elements, and high levels of dependency among system components. The dynamic nature of simulation enabled experiments in aircraft arrival rates, ground turnaround policies, airfield refueling resources, and the impact of aircraft type (F/A-18CD versus F/A-18EF) to better understand time as a cost driver for gallons of fuel consumed during ground operations. Furthermore, the stochastic simulation approach utilized in our analysis models variation, both inherent and network effects, found throughout the post-flight ground operations phase.

All data supporting this MBA Project stems from actual operational and aircraft maintenance cost data during August 2012. The dataset supporting the model's development consisted of nearly 2,600 flight events by 16 Lemoore based F/A-18 squadrons. This month was chosen for currency, complexity, and its reflection of squadrons in various phases of the 27-month FRTP training cycle. During August, NAS Lemoore air wings were returning from deployment, going on deployment, or involved in detachments to other air installations. There was even one squadron in transition from the F/A-18C to F/A-E Super Hornet (W. Straker, personal communication, May 2, 2013).

Over the next two years, 2014 through 2016, two F/A-18EF squadrons will execute a homeport shift from NAS Oceana, Virginia Beach, VA to NAS Lemoore (W. Straker, personal communication, May 2, 2013). Furthermore, six of the remaining F/A-18C squadrons in Lemoore will also transition to the new Super Hornet and represents a completely new challenge for administrative and operational stakeholders. The F/A-18EF's internal fuel capacity is 28 percent larger than the legacy Hornet, thus requiring additional servicing time between flight events (CNO, 2011a, 2012a).

A. SIMULATION

Using actual operational and cost data, a simulation was developed using the Simio software suite. Simio is a SIMulation modeling framework based on Intelligent Objects. Simio is an industry leading, object-oriented modeling framework that supports both discrete and continuous distributions as well as event, monitoring, sub-processes, and agent modeling views. Figure 6 depicts an overview of the graphical user interface as well as some of its basic functionality.

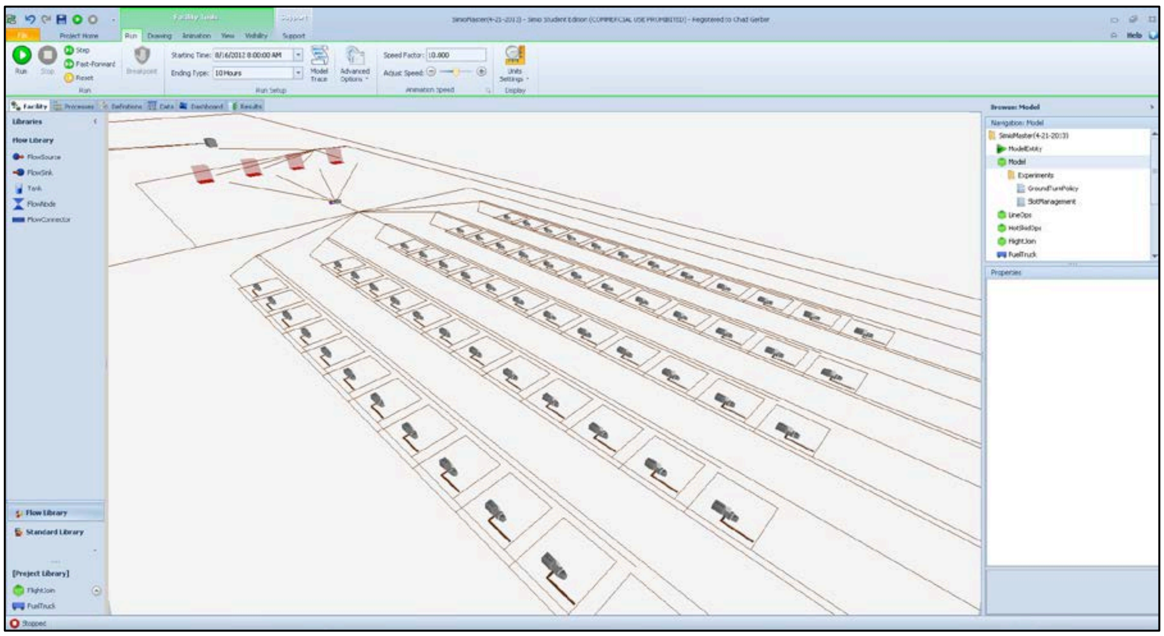

Figure 6. Simio Facility View of Airport Simulation

The first step in developing a suitable model to answer our research questions is having a thorough understanding of the current system. All data contained in this model originated from the staffs of Commander, Naval Air Forces (CNAF), Commander, Strike Fighter Wing, U.S. Pacific Fleet (CSFWP); and NAS Lemoore (NASL). Once developed, the model was validated as an accurate representation of reality. Although flight data was available for the entire operational day, this study focuses its efforts on the period of 0800 to 1759. It is during this period that the application of collaborative decision-making principles would likely yield the best results. After 1800, there are new operational planning factors to contend with, least of which are field hours, training range availability, and solar/lunar implications. Figure 7 depicts the number of aircraft arrivals by both day of the week and time of the day (T. Atkins, personal communication, January 15, 2013). Observe the hourly differences in the number of arriving aircraft exceeding 15 aircraft in some cases. This figure helped shape our assertion that the focus for this study be limited to the period from 0800 to 1759.

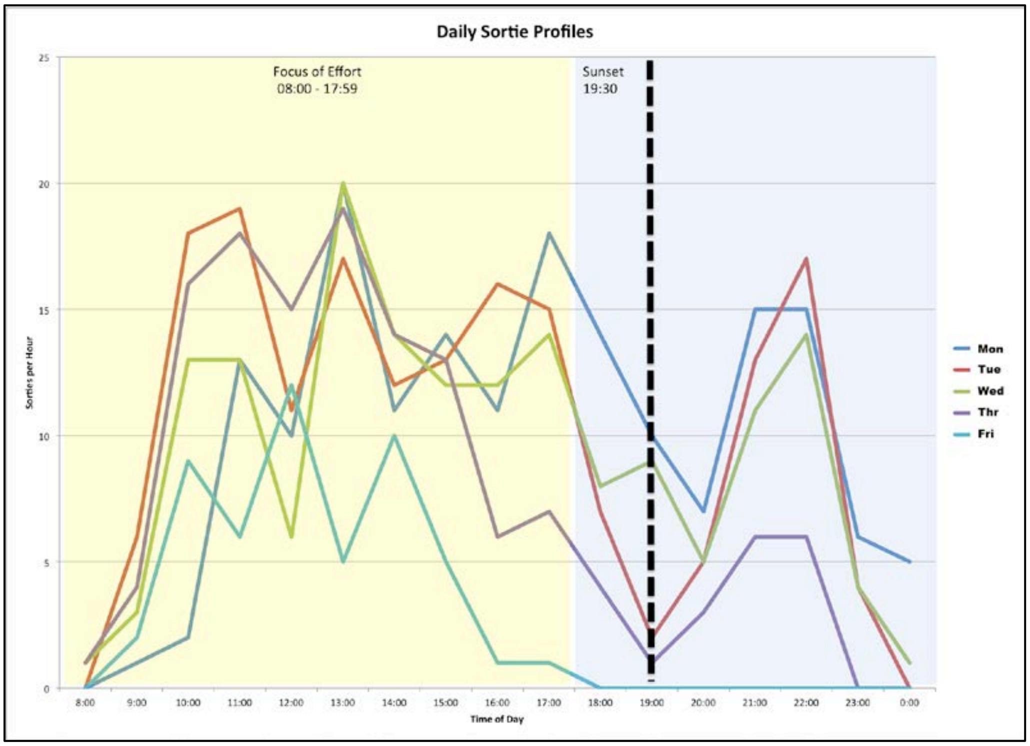

Figure 7. Daily Aircraft Arrival Patterns

Variation in aircraft arrivals is best described by the standard deviation of the mean of arriving aircraft per hour. Figure 8 depicts the range of standard deviations of arriving aircraft per hour during August 2012. Of the 21 fly days in August, two-thirds of them had variation in excess of five (T. Atkins, personal communication, January 15, 2013). Stated another way, the vast majority of flight operations at NAS Lemoore during August had differences in aircraft arrivals from one hour to the next, often in excess of 10–20 aircraft. It is this systemic attribute of military aviation operations ashore that the model is particularly optimized for study. The functional specification is revealed in the following subsections. For a more detailed model description, refer to the model specification (Appendix A) and the Simio Documentation Report (Appendix C).

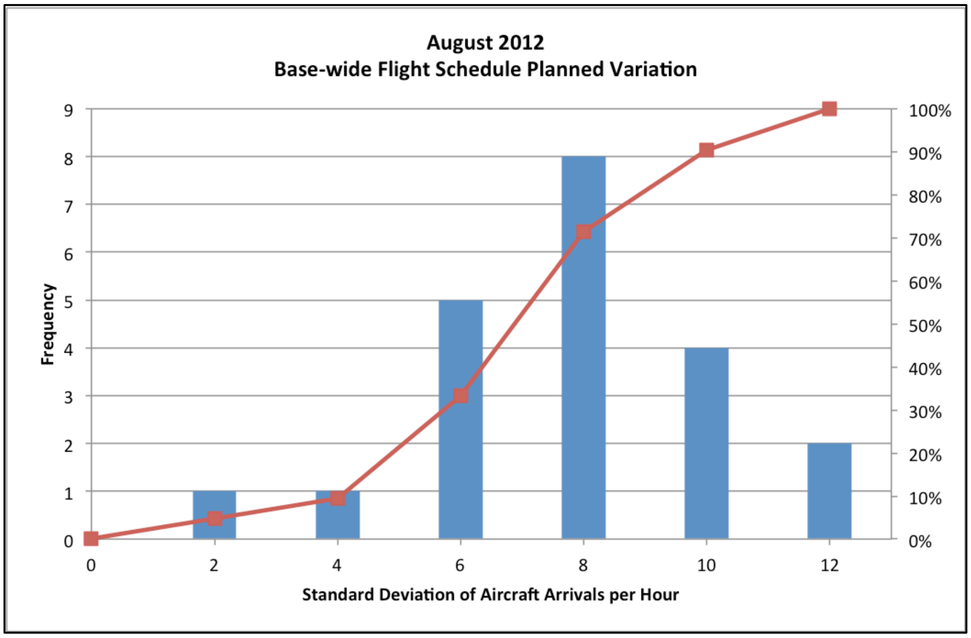

Figure 8. Variation in Aircraft Arrival Rates

1. Objective

Applying simulation and modeling techniques to our research questions facilitates the experimentation phase of the study. Since simulations, by design, can efficiently replicate the real world, introducing changes in various parameters, properties, and states while holding all other variables constant isolates cause and effect relationships. The scope of this model is from aircraft landing through engine shutdown and refueling. Although several factors influence the arrival rate of aircraft, this model abstracts from the impacts of weather, airfield emergency situations, and runway configuration changes. From the time an aircraft clears the runway until that same aircraft either launches again or shuts down in the line, statistics are recorded and analyzed. A single model run represents a 10-hour period, from 0800 to 1759. The Simio software suite is then capable of replicating a single day hundreds of times using random inputs of various seeds to produce a highly consistent and credible solution. Figure 7 depicts considerable variation in the daily arrival of aircraft. There are typically two to three peaks during the day and another large peak after sunset. Therefore, the first objective of the simulation is to better understand the impacts of aircraft fuel consumption and delay queuing from variation in aircraft arrival rate.

A second objective of the simulation is to assess the current hot skid policies aircraft ground turnaround planning and determine the costs and benefits associated with each. With an understanding of the way an airfield currently operates, we then introduce various new refueling and ground turnaround policies to determine which is best from a resourcing and planning perspective. Using a simulation has the added benefit of tying together variation in aircraft arrival rate with its impact on ground turnaround policy from a fuel consumption and total aircraft cost perspective.

The third objective of the simulation is to establish a baseline of fuel consumed in the current aircraft laydown and compare it with transitions to newer aircraft models and types in the coming years. Newer aircraft, most notably the transition from F/A-18CD to F/A-18EF, have significantly larger fuel cells requiring more time for refueling, and more time at ground idle whenever the hot skids are utilized. This model was constructed with the ability to easily change aircraft from one type to another thereby facilitating an understanding of the long-term impacts of adopting, or failing to adopt, the policy recommendations in this study.

2. Level of Detail

The constructed model was designed from the ground up to represent NAS Lemoore in central California. This air installation, along with NAS Oceana, VA, NAS Whidbey Island, WA, MCAS Miramar, CA, MCAS Beaufort, SC, and NAS Fallon, NV, make up the most significant operators of F/A-18 aircraft. In an effort to draw conclusions beneficial for all of Naval Aviation, this project’s model captures those elements common to all air installations. Specifically, multiple runways, a complex taxiway structure, multiple hangars and location, multiple flight lines at each hangar, and several spots for each aircraft to park. Additionally, each air installation is equipped with the ability to either truck or hot skid refuel. Although the time and distance relationships in the model are unique to NAS Lemoore, the model could easily be adapted to other air facilities to assess their unique challenges and opportunities. Refer to Figure 9 for an overview of the modeled airfield and the main elements, infrastructure, and asset laydown.

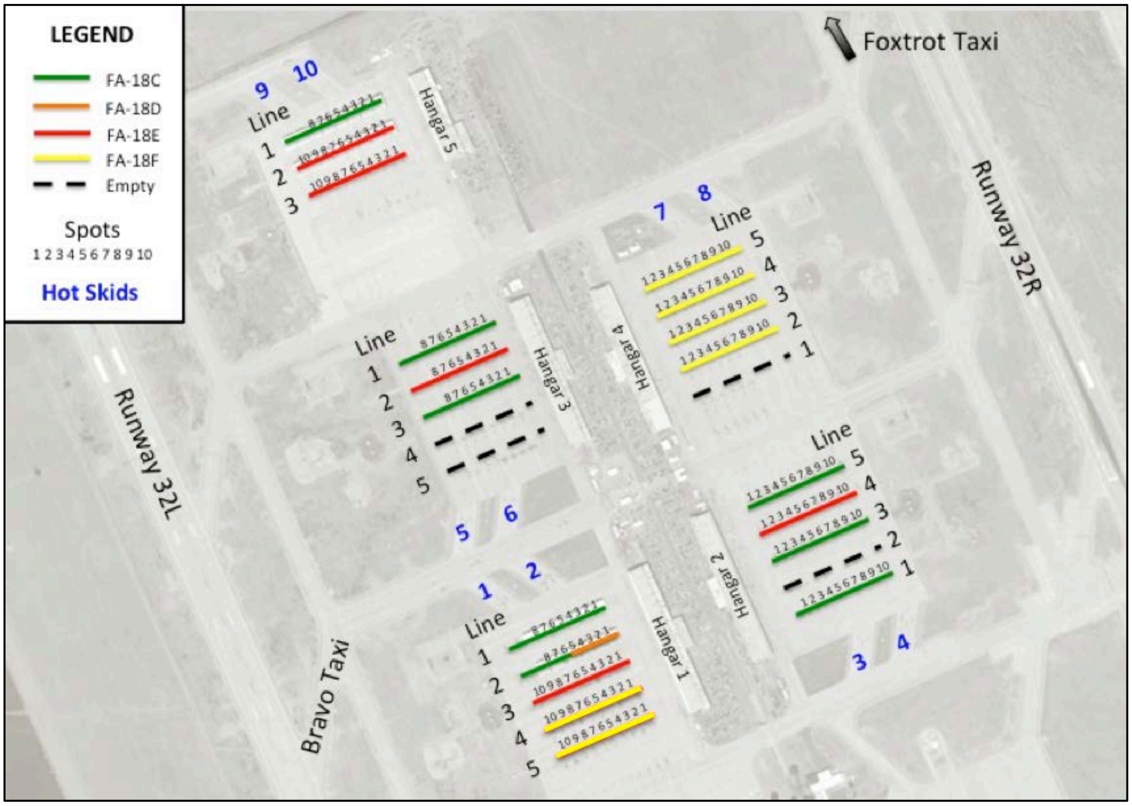

Figure 9. NAS Lemoore Hangar, Line, and Spot Layout

In answering three main research questions related to slot management, ground turnaround policy, and a look ahead to an all F/A-18EF flight line, this model captures all processes material to the decision without being overly complex. The model efficiently and effectively demonstrates the costs and benefits of various competing alternatives enabling the leadership to make well-informed decisions in the management of our nation’s precious resources.

B. APPROACH

1. Collecting Input Data

Discrete event simulation involves many data inputs. While the vast majority of inputs to the model are historical data distributions, some must be coded directly into the Simio software suite through structural decisions. In both cases, the decisions made in during data collection, analysis, and model input have a significant impact on the results.

This section presents the sources of all data input to the model. Although most data was readily available, it was often in the wrong form thus requiring further processing (i.e., fuel flow rate). In situations where no data existed, personal experience in F/A-18 operations was referenced (i.e., ordnance de-arm processing time). Special thanks go to Commander, Naval Air Forces, U.S. Pacific Fleet (N8C1); Commander, Strike Fighter Wing, U.S. Pacific Fleet (N3); Fleet Logistics Center San Diego Site Lemoore (NASL N44L); and NAS Lemoore, Air Traffic Control (N32) for making the following data accessible to our research effort.

a. Planned Flight Data

i. Naval Air Station Lemoore Tower Traffic Count Report (FY2012). This report provided the data necessary in determining the probability that an aircraft will land on Runway 32L, 32R, 14L, or 14R. This data was vital in ensuring aircraft and fuel truck taxi distances were to scale and appropriate to traffic volume. This report also captured the total number of aircraft landings to a full stop. It was important to exclude FCLP (except for the final landing), touch and go, low approaches and various other types of approaches in our analysis as each of these is not considered a landing to a full stop. Having done so would have a profoundly negative impact on the results.

ii. Naval Air Station Lemoore Daily Air Plan (August 2012). NAS Lemoore's Air Traffic Facility provided a Daily Air Plan report for 19 of 21 fly days during August 2012. These air plans served as the foundation of individual flight scheduling patterns and volume. Individual squadrons provide a copy of their signed flight schedule to station Air Operations the day prior to execution. Air Operations, in turn, aggregates each of the, potentially 16, individual flight schedules into a cohesive, single document. Contained in the final air plan is the total number of planned aircraft arrivals by the hour, total number of planned departures by the hour, number and duration of FCLP events, planned aircraft ground turnaround time, planned aircraft flight time, planned flight composition (1-, 2-, 3-, or 4-ship), and various other flight event information (T. Atkins, personal communication, January 15, 2013). It was this planned flight schedule information that was ultimately compared to actual flight information to determine variation metrics between planned and actual flight execution. This document was critical in the development of the model to simulate flight operations in the air and on the ground.

b. Actual Flight Data

i. Naval Air Systems Command (NAVAIR), Decision Knowledge Programming for Logistics Analysis and Technical Evaluation (DECKPLATE), Aircraft Readiness/Tracking Indicator Hours (August 2012). This report ensured that squadrons were only able to fly, operate, and maintain full or partial mission capable (FMC/PMC) aircraft. Typically, a squadron has many more aircraft assigned than they are funded to operate. In each case, the number of aircraft authorized to flow into a given flight schedule is determined by the squadron's R-month (27-month FRTP). Information utilized from this comprehensive report included aircraft assigned, aircraft utilization, and aircraft readiness rates to determine the probability that an arriving aircraft needs to be temporarily removed from service to repair a maintenance discrepancy (Naval Air Systems Command [NAVAIR], 2012a).

ii. NAVAIR DECKPLATE, Total Mission Requirements (TMR) Flight Report (August 2012). This report provided the total number of flights logged into and out of NAS Lemoore during August 2012. Each flight record provided the squadron name, aircraft bureau number, and, most importantly, the specific mission flown on that event (Naval Air Systems Command [NAVAIR], 2012c). Knowing the squadron, aircraft, and mission code enabled the development of a pivot table to calculate the probability that a mission involved ordnance (air-to-air, air-to-ground, or other) or was a field carrier landing practice (FCLP) event. In order for the model's objects to behave intelligently with each other as well as interface with the structure, awareness of ordnance de-arming requirements, and FCLP missions were essential.

iii. NAVAIR DECKPLATE, Naval Flight Record Subsystem (NAVFLIRS) (August 2012). This all-inclusive report provided the actual flight information for every event flown into and out of NAS Lemoore during August 2012. Contained in the report was the number of actual aircraft arrivals, exact takeoff and recovery date and time, actual number of waves an aircraft flew on a given day, actual flight composition (1-, 2-, 3-, or 4-ship), actual flight time, and various other flight event information (Naval Air Systems Command [NAVAIR], 2012b). It was this actual flight information recorded in the NAVFLIRS that was compared with the NAS Lemoore daily air plan. Placing these two documents side-by-side and using software to collate flight events by date, time, and aircraft bureau number provided an immense amount of insight into variation. Inherent variation in arrival and departure time as well as the network effects of delay as the day progresses through Wave 2, 3, and 4 was critical to building a credible and valid model.

The NAVFLIRS report provided by NAVAIR DECKPLATE aided in the development of a frequency table for aircraft type, hangar assignment, and line assignment. This analysis ensured the model routes aircraft from the runway on touchdown to their hangar/line assignment in a manner and likelihood replicating the real world.

c. Cost Data

i. Commander, Naval Air Forces, U.S. Pacific Fleet Cost Data (FY2012). This report provided the cost per flight hour (CPH) stratified by Atlantic and Pacific squadrons and was further broken down by activity type (Fleet or Fleet Replacement Squadron) and aircraft type. Once the data was paired down to just U.S. Pacific Fleet F/A-18 squadrons, based in the continental U.S., the relevant CPH could be determined. The report was extremely valuable as it broke out each aircraft CPH into its individual elements (Aviation Depot Level Repairable (AVDLR)), consumables, contracts, and fuel). Removing fuel from the calculation of CPH left the total cost per flight hour in maintenance costs. Therefore, maintenance costs consist of aircraft components repaired and returned by the supply system (AVDLR); items used to sustain or repair the aircraft (consumables); and the fixed labor contracted to sustain the aircraft (contracts) (M. Angelopoulos, personal communication, January 30, 2013).

ii. General Services Administration (GSA) FY2013 Standard Fuel Prices (Effective October 1, 2012). The Defense Logistics Agency (DLA) sets the prices for jet fuel on a quarterly basis. Figure 10 depicts a rising trend in aviation turbine fuel prices over the past three to four years. Although the current price for fuel is $4.74 (effective May 1, 2013), for the purposes of this model it is assumed that the cost per gallon of JP-5 fuel is $3.75 (M. Olszewski, personal communication, May 29, 2013; DLA, 2012). According to research in estimating the fully burdened cost of fuel (FBCF) for Naval Aviation fixed wing aircraft, this cost could be considerably higher (Truckenbrod, 2010). FBCF calculations are beyond the scope of this project and therefore abstract from fuel truck leasing, fuel services labor, miscellaneous supplies and equipment, and facilities management. Had the fully burdened cost of fuel been considered, the cost of idle operations in this report would be understated by as much as 600–700 percent (Truckenbrod, 2010). In the short run, all military and contractor personnel required to support both fuel truck and hot skid refueling operations are considered sunk and irrelevant to the policy decisions being proposed.

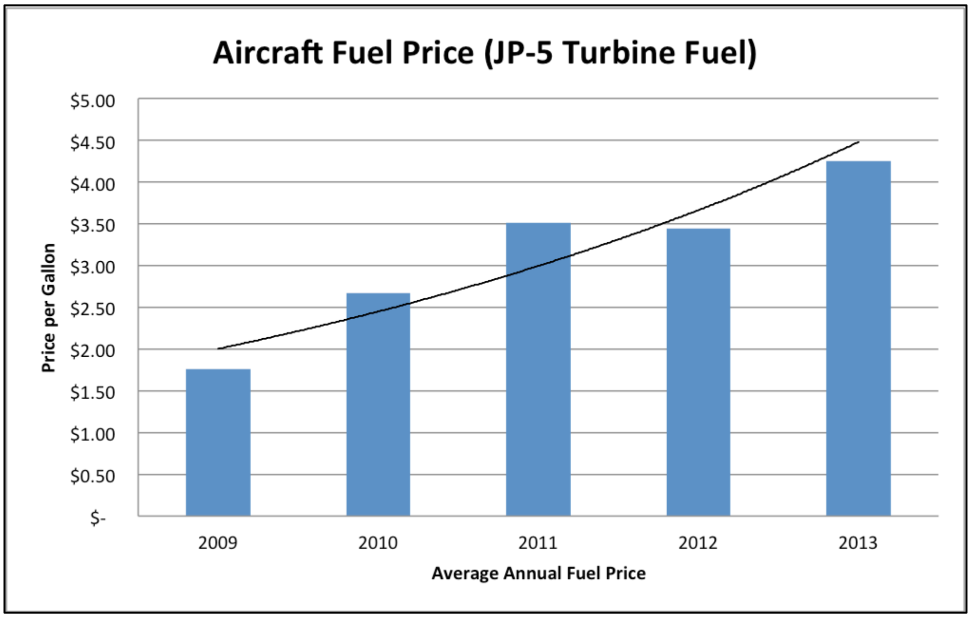

Figure 10. Defense Logistics Agency Standard Fuel Price (JP-5)

d. Airfield Data

i. Google Earth Software Output. Using Google Earth software, an elaborate network of more than 1,200 paths and 450 connectors were added to the model to provide predictable routing for aircraft and fuel trucks in and around the airport. All aircraft arriving via Runway 32L clear at either Taxiway Alpha (Hangar 2) or Bravo (Hangars 1, 3, 4, and 5). For aircraft arriving via Runway 32R, all will clear at Taxiway Foxtrot and taxi southeast toward their hangar assignment. Figure 11 depicts the mechanics behind using Google Earth to calculate ground travel distances in feet. In this example, the route depicted is for an aircraft clearing Runway 32L at Taxiway Bravo and taxiing to the hot brake check process at Hangar 1. Total distance traveled is 1,413 feet (Google, 2010).

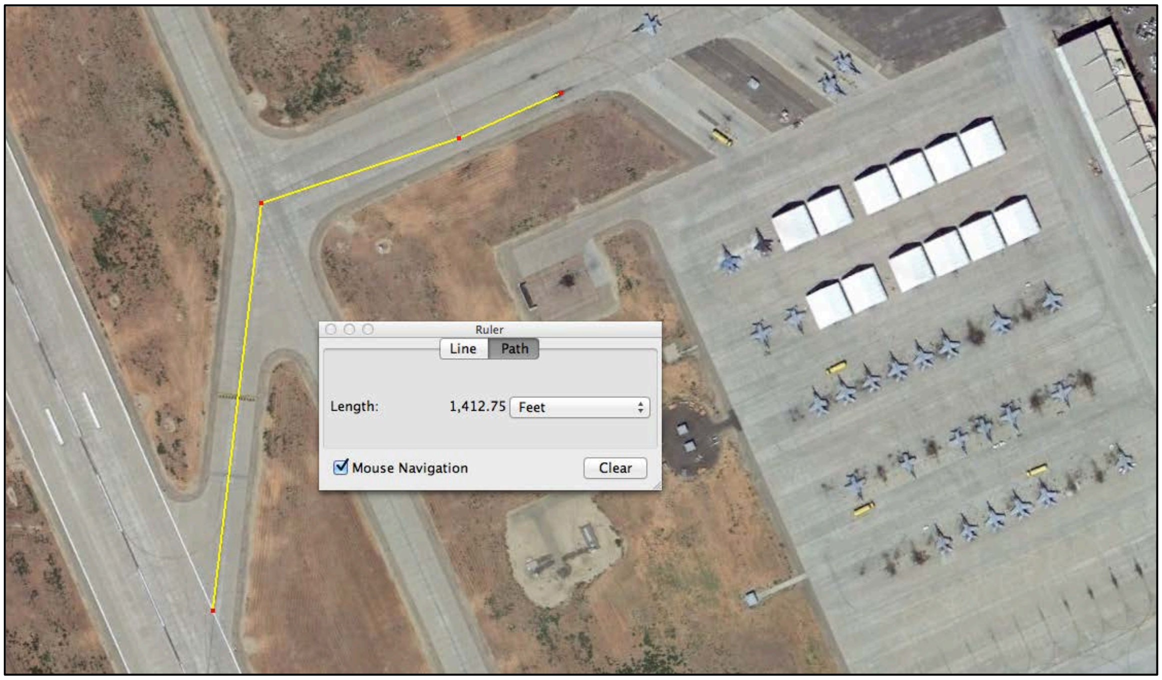

Figure 11. Google Earth Distance Calculator Screenshot (From Google, 2010)

e. Refueling Data

i. Fleet Logistics Center San Diego (FLCSD) Site Lemoore, Fuels Manager Defense Dispatch Module (August 2012). This descriptive report contains every fueling event during August 2012. Included therein is fuel transferred to aircraft from fuel trucks and hot skids, fuel truck refills via fill stands, aircraft maintenance defuels, transient aircraft refueling, and ground support equipment refueling. All transferred fuel quantities in the report were expressed in gallons and were identified by date and time requested, dispatched, and completed; activity, modex (three digit serial number on nose of aircraft), bureau number (BUNO), and aircraft type; and the unique identifier of the fuel truck or hot skids providing the service (G. Blocker, personal communication, January 16, 2013). Cumulative probability tables were then created by aircraft type and refueling method. Refer to Appendix A for those distributions.

ii. NAS Lemoore, Fuel Facilities, Monthly JP-5 Cost Accounting Report (August 2012). This report identified specific squadron usage rates of fuel truck and hot skid refueling. Although some squadrons tended to utilize the hot skids more than others during August, a cumulative distribution function was created for entry into the model applying the same likelihood to all squadrons during the experimentation phase (S. Cotta, personal communication, January 25, 2013). The model first determines the type of aircraft requesting fuel services and then applies the appropriate fuel demand distribution.

2. Building the Model

The goal of any simulation is to mimic the behavior of a real world system with a model that “thinks” and acts in similar fashion. Developing a simulation to mimic the ground operations of Naval Air Station Lemoore provided the means with which to answer not only our research questions, but many more in the years to come in future academic projects. The model was developed incrementally by focusing first on individual elements before bringing them all together. Planning, analyzing, designing, implementing, and testing the model in smaller portions of the whole proved to be extremely efficient. This methodology reduced the risk of rework, enhanced standardization in coding, and ensured only the best software development practices were integrated into the larger model.

There were four phases of model development used in the construction of the airport model. The first phase allowed aircraft to arrive at the airport, conduct hot skid refueling, and then takeoff again. In this phase, there were no fuel trucks available, no aircraft aborts (maintenance, inability to takeoff within 20 minutes of planned departure, etc.), and no aircrew swaps. The second phase added in aircrew swap functionality for subsequent waves yet still restricted the use of truck refueling and aircraft aborts. In the third phase, fuel trucks were introduced along with the hot skids and aircrew swaps. At this point the model was nearing completion. The final phase allowed aircraft to abort for timing, maintenance, or insufficient refueling resources.

For the model to be useful, it must accurately account for variation in all processes across the modeled airport. Variation in any process has a much greater impact on the results than the average. Therefore, at no time in the model’s development was a mean, or average, used in place of a distribution. When no data existed, a triangular distribution was used to represent the dataset. Triangular distributions use just three parameters to define their shape; the minimum, mode (most common), and maximum values. When data was readily available but in the wrong form, statistical analysis was performed to get the data into a format suitable for modeling.

For the most part, a large volume of data was available paving the way in developing a theoretical distribution of the data. Goodness of fit software was utilized including Stat::Fit by Geer Mountain Software Corporation and EasyFit by MathWave Technologies. Both software applications simplified the process of finding the best fit by ensuring analysis errors were minimized and decisions about the best distribution to use were optimized.

The main research question answered by the model is how fuel consumption is impacted by a reduction in aircraft arrival variation per hour. Since flight event arrivals are independent and random, they are best modeled using a Poisson process distribution. An attractive feature of using Simio is that it fully supports changing arrival rates over time. Also called a step-wise linear arrival rate, Simio is well equipped to handle aircraft arriving at differing Poisson distributions with each passing hour of the day.

Simulating the operations at an airfield is similar to a host of related operations management problems including restaurant reservations, hotel capacity management, and checkout lines at the local grocer. In each case there is a multiple-queue, multiple-server system. All aircraft (customers) enter through one of two runways (82 percent Runway 32L and 18 percent Runway 32R) leading to a series of processes (T. Atkins, personal communications, January 15, 2013). Each process has a fixed service capacity and when taken in totality, the entire airport is only as capable at its slowest process. When complete with the necessary ground operations processes, the aircraft departs the system through either the engine shutdown process or launches on a subsequent wave. Refer to Figure 12 for an overview of the ground operations processes captured in the model. Simio's robust statistical analysis toolbox enables metrics to be collected on every server, process, path, aircraft, and fuel truck. In building the model, keen attention was paid to which metrics were most important (utilization, time in system, time in queue, number in system, number in queue, etc.) and were ultimately validated in subsequent phases of development.

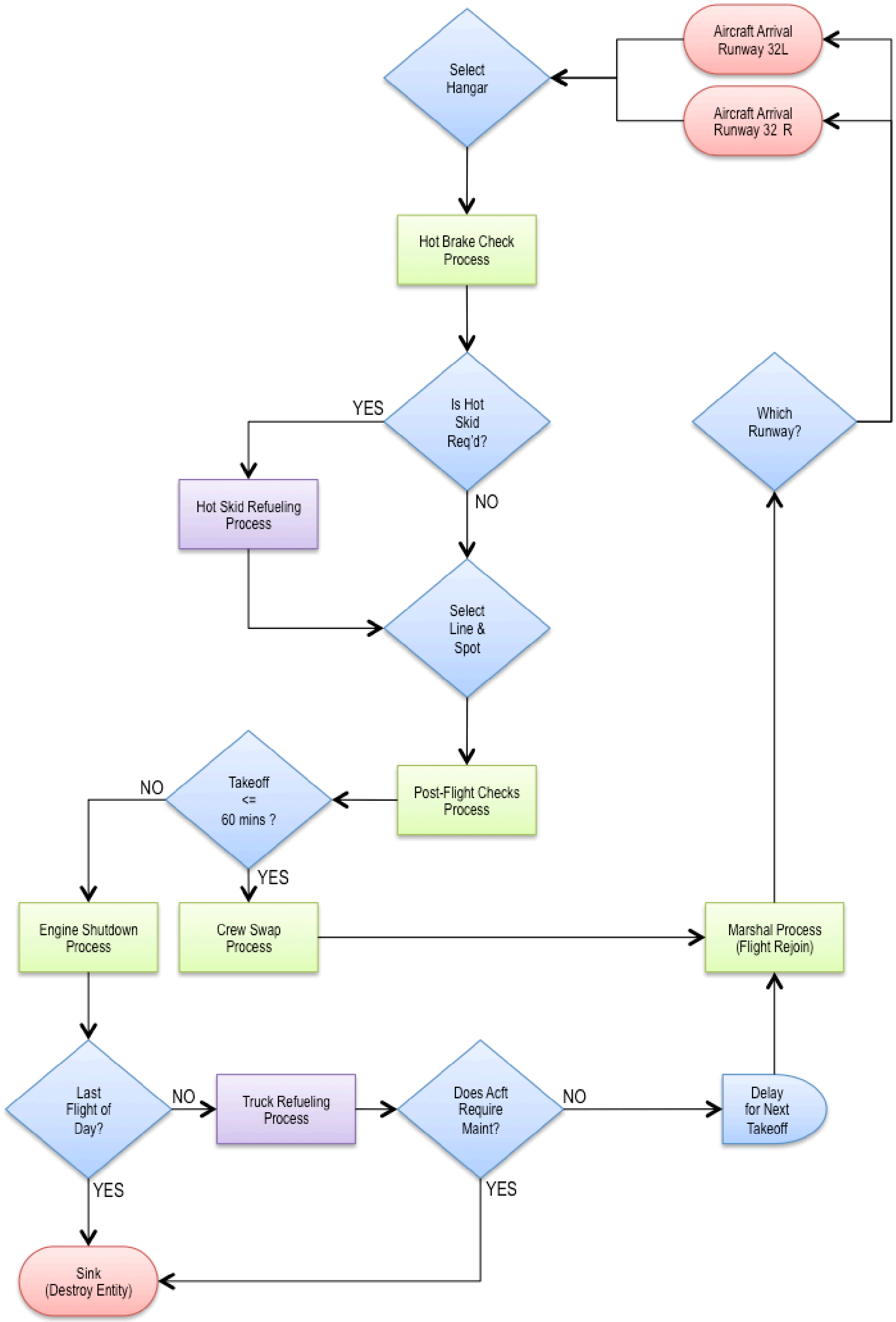

Figure 12. Ground Operations Process Overview

3. Validating the Model

The model mimics a 10-hour fly window from 0800 to 1759, Monday through Friday, at a single air installation. The first hour, 0800 to 0859 is considered the warm-up period where the model accelerates to steady state. All statistical calculations including standard variation, coefficient of variation, and average sorties per day were computed abstracting from the first hour. In fact, all time varying arrival tables used a "0" for the number of aircraft arrivals in Hour 1. Important to note is that each experiment was run using 250 replications (Figure 13), or 2,500 hours of ground operations. This essentially reduced all of the potential negative impacts from not being a steady state to near zero.

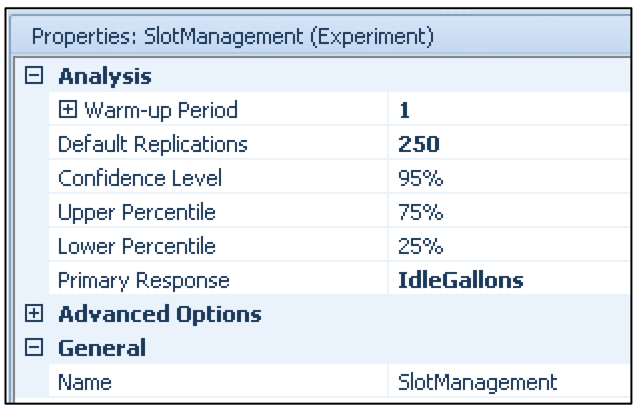

Figure 13. Minimize Sampling Error through Replication

4. Conducting Experiments

a. Slot Management Policy

Managing arrival slots is a technique widely used in the commercial aviation industry. Under the philosophical veil of collaborative decision-making, slot management requires a shared view of the operational environment by several stakeholders and knowledge of the tradeoffs that decisions have on the system. Understanding how cost responds to changes in arrival rate will determine how much control on the flow of aircraft is required to minimize cost.

Using historical operational and cost data, the slot management experiment tests the impact of reducing variation in the arrival of aircraft at an airfield. There are 12 scenarios planned in support of slot management. The simulation typically runs 250 replications at each of 12 different standard deviations of the mean of arriving aircraft per hour between 0 and 11. All variables are held constant throughout the entire experiment including aircraft type (Table 1), ground turnaround timing policy (Figure 14), and the number of fuel trucks in operation. Aircraft type mimics the NAS Lemoore flight line during August 2012. This particular month represents the dynamic nature of military airfield operations with squadrons departing on detachments to other air installations and entire air wings of three or four squadrons departing or returning from extended deployments (T. Atkins, personal communication, January 15, 2013).

Aircraft Type							
Aircraft Type	Probability	Hangar 1	Hangar 2	Hangar 3	Hangar 4	Hangar 5	Totals
FA-18C	30.8%	3.4%	17.5%	9.0%		0.9%	30.8%
FA-18D	4.1%	4.1%					4.1%
FA-18E	26.5%	13.8%	2.3%	3.2%		7.1%	26.5%
FA-18F	38.6%	23.9%			14.7%		38.6%
Totals	100%	45.2%	19.9%	12.2%	14.7%	8.0%	100%

Table 1. Aircraft Type Probability Table (August 2012)

In an effort to isolate the impact of reducing variation on gallons of fuel consumed and cost during post-flight ground operations, this experiment restricts ground turnaround time to a value greater than 60 minutes. The hot skids are still operational, however, for pre-flight planning purposes, aircraft must plan to use the fuel trucks to the maximum extent practicable (Figure 14). Fuel truck resources are also held fixed at 10 fuel trucks throughout the experiment. There are eight 10,000 gallon and two 8,000 gallon fuel trucks in continuous daily service from 0800 to 1759. Furthermore, each fuel truck is allowed to deplete its internal fuel capacity to 2,500 gallons before signaling to refill at a fill stand.

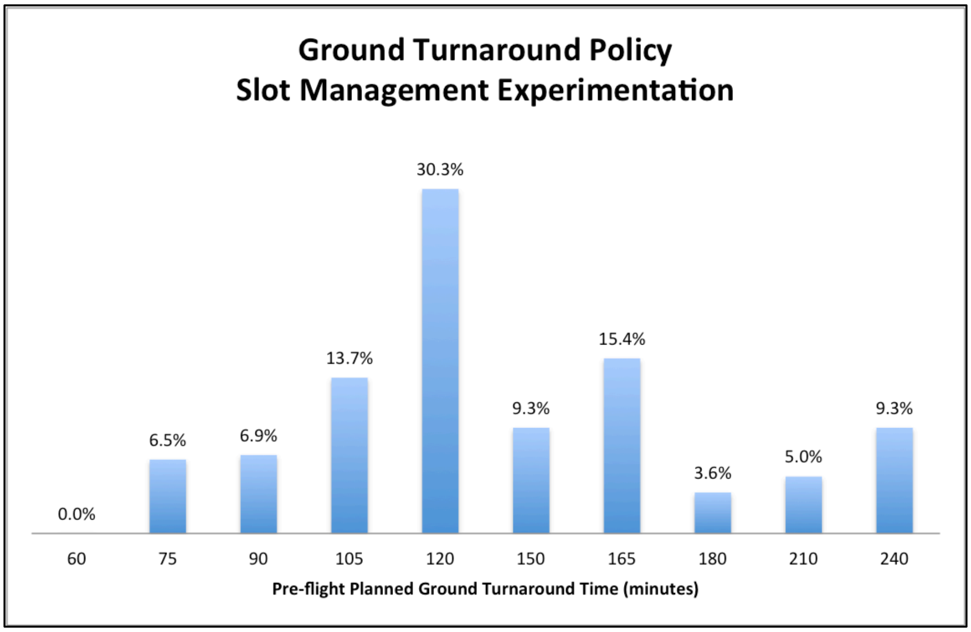

Figure 14. Ground Turnaround Timing for Slot Management Experiments

Reducing the standard deviations of the mean of arriving aircraft per hour in increments of one allows for both trend and marginal cost analysis. The worst arrival variation during the month was 10.9 on August 20, 2012 (T. Atkins, personal communications, January 15, 2013). This value serves as the limiting standard deviation in the extreme. On the other end of the variation spectrum is when the standard deviation of the mean of a set of arriving aircraft per hour is 0. This is also known as perfectly balanced. Determining the number of aircraft arriving in any hour is a linear formulation between the worst-case scenario (standard deviation equals 10.9) and the theoretical best-case scenario (standard deviation equals 0).

This experiment reveals little in the form of total gallons of fuel consumed or aircraft maintenance cost expenditures due to inconsistencies in the number of aircraft generated per hour during model run. The range of arriving aircraft from one replication to the next ranges from 102 to 110 aircraft. For this reason, the focus of effort is on the average time, in minutes, an individual aircraft spends at ground idle during post-flight operations. In calculating the total cost savings, the average time avoided per aircraft is multiplied by the annual number of sorties expected from 0800 to 1759. It is during this phase of flight that we find no contribution to tactical proficiency and operational readiness. As such, the objective function of each slot management experiment is to minimize gallons of fuel consumed (Figure 15).

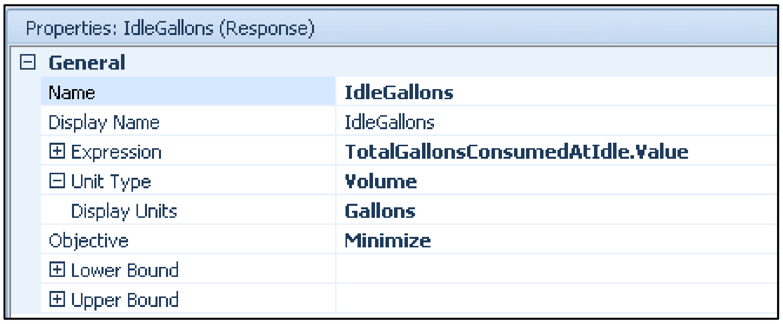

Figure 15. Slot Management Objective Function

The deliverable from this experiment is a recommendation to leadership on the benefits of managing aircraft arrival rates through slot management. If the data suggests implementing a policy forcing collaboration among individual squadrons is substantially beneficial in reducing fuel consumption, then a recommendation for the standard deviation of the mean of arriving aircraft per hour will be provided. On the other hand, if the solution to this experiment turns out to be unfavorable, a recommendation will be made to avoid such a policy.

b. Ground Turnaround Time Policy

On November 23, 2011, Commander, Naval Air Forces issued a mandate for all aircraft refueling to leverage the fuel trucks to the maximum extent practicable (Myers, 2011). The normal time required to turn an aircraft around between flight events is two hours. However, anytime a flight schedule is planned with a ground turnaround time of less than one hour, hot skid refueling is required (Figure 16). There simply isn’t enough time to land, taxi back to the line, shutdown, dispatch a fuel truck, complete the required ground maintenance service requirements, and man up the aircraft for the next event in 60 minutes or less. Analyzing over 2,600 flight events and 4,300 refueling events provided much insight into the operational and administrative behavioral patterns of F/A-18 squadrons.

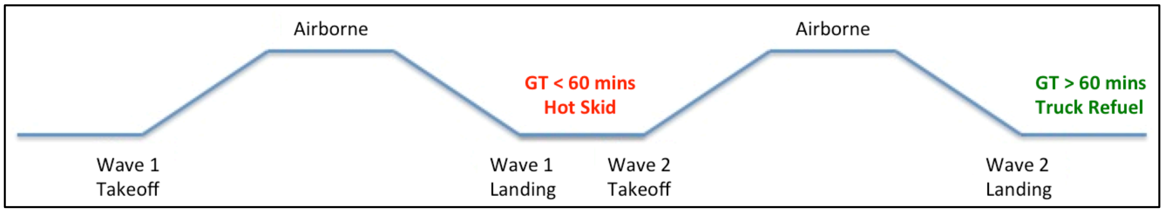

Figure 16. Ground Turnaround Timing Example

The purpose of this experiment is to first baseline the entire airport's fuel consumption during post-flight operations and then to systematically implement three additional ground turnaround time policies. Each scenario will progressively restrict the use of hot skids during preflight planning and plot the resulting response curves. Scenarios include the current (baseline); a maximum of 20 percent of all missions have ground turns less than or equal to 60 minutes; a maximum of 10 percent of all missions have ground turns less than or equal to 60 minutes; and only those missions requiring a turn of less than or equal to 60 minutes (FCLP only).

This experiment is tied directly to the results of the slot management experiment. The recommended standard deviation of the mean of arriving aircraft per hour in slot management will serve as the principal assumption in this experiment. Even if leadership rejects the slot management recommendation, the marginal changes in gallons of fuel consumed and aircraft operating costs from changes in ground turnaround policy remains valid. Holding the variation in arrival rate constant at the recommended level, each of the incremental changes in ground turnaround time are introduced, analyzed, and recorded for further analysis. Other significant assumptions in this experiment were to hold the fuel trucks in service constant at 10 (eight 10,000 and two 8,000 gallon trucks) and to have them refill when their internal fuel capacities reach 2,500 gallons of fuel remaining.

The true value in this experiment is from incremental changes in both gallons consumed and aircraft operating costs on a per aircraft basis as ground turnaround policies are introduced. This experiment will show how sensitive the time spent per aircraft at idle during post-flight ground operations truly is to each policy. If the time per aircraft is reduced by policy, there is also a reduction in gallons of fuel consumed. Here again, just as in the slot management experiment, there is no contribution to tactical proficiency or operational readiness in the post-flight phase. As such, the objective function of each ground turnaround policy experiment is to minimize gallons of fuel consumed (Figure 15).

c. F/A-18EF Transition

The final experiment in this MBA project is to assess the cost of inaction in adopting a slot management policy or a ground turnaround policy, or both. Strike Fighter Squadron 122, the West Coast Fleet Replacement Squadron, ceased F/A-18CD flight operations on September 30, 2012 (CNO, 2012b). Their operational foot print is being replaced with two East Coast F/A-18EF squadrons changing their homeport to NAS Lemoore as well as six additional F/A-18C to F/A-18EF transition between now and 2016 (W. Straker, personal communication, May 2, 2013). By 2016, the entire flight line will behave differently. The current organizational behavior and culture must adapt to this reality and think critically about what this means for routine ground operations.

In this experiment we adjust the model to an all F/A-18EF flight line. All F/A-18C squadrons become F/A-18E or F and F/A-18D become F. The new mix of aircraft type is depicted in Table 2. Of note, precise hangar assignments of the two squadrons moving from NAS Oceana, Virginia Beach, VA was not known at the time of this project. Therefore, it was assumed for the purposes of this model that they move into Hangar 1 by occupying the spaces vacated by VFA-122's former F/A-18CD aircraft. This is the most conservative assignment possible. Other assumptions critical to this experiment were holding the number of fuel trucks constant at 10 (eight 10,000 and two 8,000 gallon trucks) and signaling trucks to refill when the remaining fuel falls below 2,500 gallons.

Aircraft Type in 2016 (F/A-18EF Only)							
Aircraft Type	Probability	Hangar 1	Hangar 2	Hangar 3	Hangar 4	Hangar 5	Totals
FA-18E	50.6%	17.2%	13.1%	12.2%		8.1%	50.6%
FA-18F	49.4%	28.0%	6.7%		14.7%		49.4%
Totals	100.0%	45.2%	19.8%	12.2%	14.7%	8.1%	100.0%

Note: Hangar assignments of the two squadrons relocating to NAS Lemoore is pre-decisional.

Table 2. NAS Lemoore F/A-18EF Only Flight line by 2016

In this experiment, a side-by-side comparison is made between the current (August 2012) flight line configuration and the future squadron laydown in 2016. Each flight line composition, 2012 and 2016, is subjected to two arrival variations and two ground turnaround policies. Upon completion of each scenario, the results are plotted in response curves highlighting gallons of fuel consumed and aircraft operating cost. The two aircraft arrival variations leverage lessons learned in the slot management experiment and represent the most common and recommended slot policy.

The first scenario uses the most common arrival variation at a standard deviation of the mean of arriving aircraft per hour at 7.0. This is the most likely variation threshold based on historical flight scheduling patterns. This scenario will also use the current (baseline) or status quo ground turnaround policy where 36.9 percent of all planned ground turns are less than or equal to 60 minutes (G. Blocker, personal communication, January 16, 2013).

The second scenario also used the most common arrival variation at a standard deviation of the mean of arriving aircraft per hour at 7.0. However, in this scenario, the ground turnaround policy is reduced from status quo (36.9 percent) to 10 percent of all ground turns being less than or equal to 60 minutes between events.

The third and final scenario in this experiment combines the recommended arrival variation from the slot management experiment with a 10 percent ground turnaround policy. This combination should provide the greatest cost savings regardless of flight line composition.

C. MODEL SCOPE AND DEFINITION

Aircraft destined for NAS Lemoore arrive at varying rates to one of two parallel runways. The airfield's theoretical capacity to launch and recover aircraft greatly exceeds its normal flight operations demand (T. Atkins, personal communication, January 15, 2013). However, anytime a steady state process is subjected to high levels of variation, such as aircraft arrival rates, delay queues develop and propagate throughout the airfield in any of several ground operations processes. The objective of this model is to quantitatively measure the effects of queuing on all aircraft and refueling processes from aircraft touchdown through engine shutdown. This section outlines the most significant data inputs supporting the simulation's construction. Specific model attributes can be found in Appendix A of this report. Furthermore, a complete software documentation report is available online. Refer to Appendix C for details.

1. Model Entry

Aircraft arrive through one of two sources; primary and secondary. All flight events are comprised of one or more flight members in one or more flight waves. Regardless of flight membership, one, two, three, or four flight members, the primary source is responsible for generating all Wave 1 sorties. As flight schedules in an operational F/A-18 squadron are planned in a logical manner permitting a single aircraft to fly many times throughout the day, so too does the model built for this project. Considering the first flight of the day for a unique aircraft originates from the primary source, all subsequent waves (two, three, or four) originate from the secondary source.

The primary source generates Wave 1 aircraft arrivals according to a non-stationary, Poisson, time varying arrival rate (Table 3). In this model, the airfield's operations do not commence until 0800 and, although aircraft can arrive within the first hour of operations, the planned flight schedule does not have any arrivals until after 0900. The number of aircraft arriving in each flight depends on the result of a discrete random number between one and four aircraft based on historical data. Once the model knows how many flight members there are, it must now determine the aircraft type by selecting an F/A-18C, D, E, or F from a squadron probability lookup table (Table 4). This table allocates a unique percentage of all sorties to a specific squadron. For example, in the first row of Table 4, VFA-122 F/A-18C's represent 3.4 percent of all daily sorties flown (NAVAIR, 2012b).

Hour	Max Arrival Per Hour
2/28/2013 8:00:00 AM	0
2/28/2013 9:00:00 AM	9
2/28/2013 10:00:00 AM	8
2/28/2013 11:00:00 AM	10
2/28/2013 12:00:00 PM	11
2/28/2013 1:00:00 PM	19
2/28/2013 2:00:00 PM	10
2/28/2013 3:00:00 PM	14
2/28/2013 4:00:00 PM	9
2/28/2013 5:00:00 PM	17

Table 3. Time Varying Arrival Table

Squadron Table (Current, 2012)					
Squadron	**Aircraft Type**	**Squadron Probability**	**Hangar Select Node**	**Line Select Node**	**Max Aircraft**
VFA1_C1	1	3.4%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line1	10
VFA1_D2	2	4.1%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line2	4
VFA1_E3	3	13.8%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line3	11
VFA1_F4	4	12.0%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line4	11
VFA1_F5	4	11.9%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line5	12
VFA2_C1	1	5.4%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line1	5
VFA3_C2	1	0.0%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line2	0
VFA4_C3	1	5.4%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line3	5
VFA5_E4	3	2.3%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line4	7
VFA6_C5	1	6.7%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line5	5
VFA7_C1	1	3.6%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line1	5
VFA8_E2	3	3.2%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line2	7
VFA9_C3	1	5.4%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line3	5
VFA10_F2	4	3.4%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line2	8
VFA11_F3	4	5.7%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line3	8
VFA12_F4	4	4.0%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line4	8
VFA13_F5	4	1.6%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line5	8
VFA14_C1	1	0.9%	TransferNode_Hangar5	TransferNode_Hangar5_Line1	5
VFA15_E2	3	0.9%	TransferNode_Hangar5	TransferNode_Hangar5_Line2	7
VFA16_E3	3	6.3%	TransferNode_Hangar5	TransferNode_Hangar5_Line3	6

Table 4. Squadron and Aircraft Ready for Tasking

Assuming the number of aircraft arriving in the current hour does not exceed the maximum allowable per the time varying arrival table, the aircraft are allowed to enter the model. The initial flight time was determined using historical data based on more than 2,600 flight events by Lemoore based aircraft (NAVAIR, 2012b). Considering the F/A-18CD has a significantly smaller internal and external fuel capacity, it is important for the model to be sensitive to aircraft type (CNO, 2011a, 2012a). The planned flight time in the simulation behaves similarly to the real world in that aircraft rarely land at precisely their scheduled land time. In fact, the general trend is to land later than planned by an increasing margin as the fly day progresses.

Although the actual arrival time is normally distributed about the planned land time, the model ensures both the actual flight time and the actual ground turnaround times are adjusted for variation in arrival rate. Variation in planned arrival time represents the inherent variation in every flight event. The second type of variation is how the early or late arrival of an aircraft affects the availability of ground refueling resources and the timing for Waves 2, 3, and/or 4. Ensuring both inherent variation in the arrival of aircraft and the effects of delay propagation throughout the fly day are very important attributes captured in this model.

The variation in actual aircraft arrival could be either positive or negative. If positive, the aircraft lands past its planned time of arrival, the actual flight time is longer than planned, and the time remaining on the ground to turnaround the aircraft before the next event, if applicable, is shortened. On the other hand, whenever arrival variation is negative, the aircraft lands early resulting in a shortened actual flight time and more time to turn the aircraft around prior to the next wave, when appropriate. In the rare case that the arrival variation so negative that the resulting arrival time is prior to the field opening, the aircraft simply arrives at the start of flight operations, or 0800.

The primary source will continue to generate flight events throughout the day so long as the maximum number of aircraft in the time varying arrival table are not exceeded in any given hour. Furthermore, the model also monitors the time of the day and its proximity to the airfield's closure. Just as a squadron would not plan a two-ship to fly four waves starting at 2200 in the evening, so too the model is sensitive to the time of day. Our research analyzed 21 fly days in August 2012 and successfully patterned the maximum number of waves based on the time remaining in the airfield's flight operations window. If a squadron's flight schedule calls for an aircraft to fly four waves, it must takeoff prior to 1200; three waves, prior to 1500; two waves, prior to 1800; and one wave can launch at any time during the field's normal hours of operation (T. Atkins, personal communication, January 15, 2013).

The next step in the algorithm of introducing an aircraft at the primary source (Wave 1) is to ensure that Ready for Tasking (RFT) limits are not exceeded. Each of the operational squadrons represented in this study were at different points in the 27-month FRTP. Those squadrons closer to deployment were funded to fly and maintain a larger number of aircraft while those squadrons recently returning from deployment were authorized to fly and maintain just a few (NAVAIR, 2012a). For example, a squadron may have 12 aircraft assigned to their unit and be authorized just five for their daily flight schedule. This maximum aircraft availability number is captured in the column titled "Max Aircraft" of the squadron table (Table 4).

2. Wave Timing Logic

To better understand the model's structure, organization, and implementation, an understanding of flight event wave timing is necessary. Taken one step further, understanding wave timing ensures readers understand the effects of both inherent and systemic delay queuing problems. Using the example provided in this section, Figure 17 depicts the timing elements of a planned ("rough") flight schedule in green and actual ("smooth") timing variables in red. Using Figure 17 along with Table 5, Wave Timing Variables, will aid the reader's understanding of our wave timing algorithm.

Wave Timing Variables		
D1	Planned Last Departure Time	= A1 - FT
FT	Planned Flight Time	Random.Discrete (see appendix)
A1	Planned Arrival Time	Equals the time of Primary source creation
A1'	Actual Arrival Time	= A1 + arrival variation (see appendix)
GT	Planned Ground Turnaround Time	Random.Discrete (see appendix)
D2	Planned Next Departure Time	= A1 + GT
Special Variables for Subsequent Waves		
Delta	Dynamic State Variable	= Current Time - D2
D1'	Actual Departure Time	= Current Time
A1'	Actual Arrival Time	Random.Discrete (see appendix)

Table 5. Wave Timing Variables

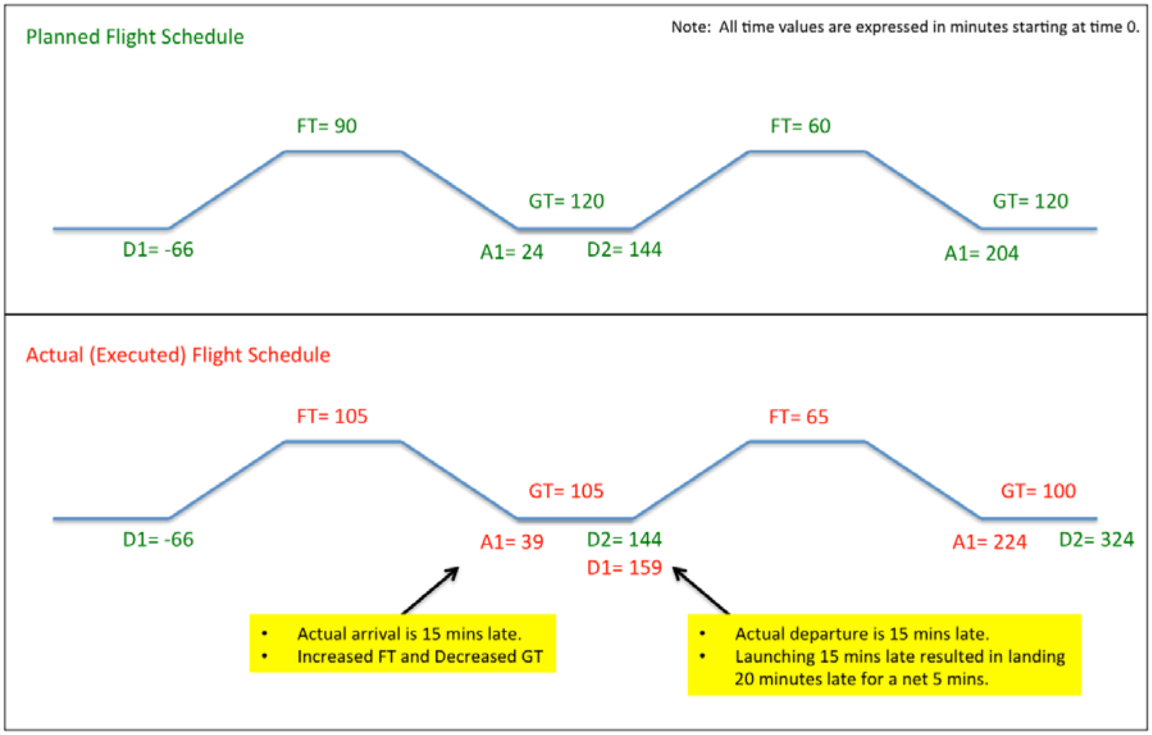

Figure 17. Wave Timing Example

The planned flight schedule is first developed by the primary source when an aircraft or flight is first initiated. Since this model's focus of effort is on controlling the arrival of aircraft (A1), this variable is the value from which all others are initially derived. Using the current model time as the time an aircraft is scheduled to land from the primary source, deriving the planned takeoff time (D1) is simply the current time minus a randomly generated flight time (FT). Should a specific aircraft be required in a subsequent wave, the planned departure time (D2) is simply A1 plus a randomly generated ground turnaround (GT) time. At this point, all of the elements of a planned flight schedule are intact; takeoff time, flight time, land time, and ground turnaround time (if applicable). The top half of Figure 17 shows the planned flight schedule. Since aircraft rarely land exactly when they are supposed to, the actual arrival time must be updated to reflect the addition or subtraction of a randomly generated time offset and stored as A1'. If the calculated arrival variation of an aircraft arriving in Wave 1 is a positive value, the aircraft will delay at the primary source until the updated (A1') time of arrival. If the arrival variation is negative, the aircraft will enter immediately and experience a shortened actual FT and longer than planned GT.

Once an aircraft clears the runway, the ground operational processes commence. The actual time remaining for a proper aircraft turnaround depends on the resulting A1'. If landing excessively late, an aircraft once scheduled to receive refueling via fuel truck may actually be required to route through the hot skids for fuel servicing. The model is not only responsive to this unknown but also variation in the following:

- Hot brake check process variation
- Hot skid availability
- Fuel truck availability
- Fuel demand variability (by both aircraft type and method of refuel)
- Post flight check process variation
- Aircrew swap process variation (if hot skid refueled)
- Engine shutdown process variation (if fuel truck refuel or last flight of the day)
- Marshal timing variation (if launching on a subsequent wave)

In the most optimal situation, an aircraft will complete hot brake checks, taxi to and shutdown in their respective flight line, and receive refueling via fuel truck. Or, in the event there is insufficient fuel truck capacity forecasted prior to their next departure time (D2), the aircraft proceeds through the hot skids and then shuts down in their respective flight line. In either case, the aircraft will delay in the line until D2. At time D2, all flight members will taxi out together to marshal where they complete their remaining pre-flight checks and establish communications with one another. If the current model time minus D2 is zero, the aircraft is launching on time. Since the model is only concerned with capturing the time an aircraft spends on the ground, all of the timing variables are updated just prior to takeoff on the subsequent wave to reflect the next line in the planned flight schedule:

- New D1 is set equal to the old D2
- New A1 is set equal to new D1 plus new randomly generated FT
- New D2 is set equal to the new A1 plus new randomly generated GT

The new D1 is then updated to reflect the current model time and stored as the actual takeoff time (D1'). In this case, the aircraft is taking off in accordance with the planned flight schedule and therefore is experiencing no effects of variation from prior waves; A1 and A1' are the same. Important to note is the actual FT is simply the difference between D1' and A1' and bears no consequence on the model. It is assumed that if an aircraft launches within 20 minutes of their planned takeoff time, the mission is executed as planned. On the other hand, if the flight is unable to get airborne within 20 minutes of their planned departure time, the flight is aborted, the aircraft taxi back to their respective line, and the aircraft are preserved in support of subsequent waves.

In the rare event that an aircraft is scheduled to fly again and there is insufficient fuel truck capacity to ensure servicing prior to 30 minutes of D2, a hot skid is required to ensure success. This assessment is made while in the hot brake check process. Taken one step further, if there is no fuel truck or hot skid available, the entire flight is aborted, taxied back to the line and shutdown in order to preserve the aircraft for subsequent waves. Assuming a fuel truck could not be guaranteed prior to 30 minutes of the planned next departure and the hot skid was available, the aircraft refuels in the hot skid and then proceeds to the line to shutdown where it awaits its next scheduled launch (D2).

In extreme situations, the combined delays from A1' and the various queues of the ground processes result in a departure attempt greater than 20 minutes past the planned departure. When this occurs, the entire flight is flagged to abort. At no time is a partial flight launched in the simulation. Instead, the primary and secondary sources are monitoring aborting aircraft and respond accordingly in order to manage the maximum aircraft required by the time varying arrival table. Therefore, an aborting aircraft and its wingman taxi back to their respective line from their current location on the airfield and shutdown regardless of the number of subsequent waves scheduled. The primary and/or secondary sources of aircraft arrivals create or release aircraft thus ensuring a consistent and predictable aircraft arrival rate suitable for further analysis.

Given the extreme situation outlined above, the more likely situation is that the flight attempts to launch within 20 minutes of its planned departure time. Any attempt to launch within 20 minutes of D2 is considered acceptable to any scheduled mission. The flight and all of its members (Dash 2, 3, or 4) join in marshal, complete their pre-flight checks, establish communications with one another, and takeoff.

In our research, however, it was determined that the time a flight lands on a subsequent flight is directly correlated to the time it launched. For example, an aircraft launching five minutes late had a 47 percent chance of landing on time while an aircraft launching 15 minutes late a mere 10 percent chance of landing on time. To simplify implementing this logic, we stratified the maximum of 20 minutes allowed for launching late into one of five categories (0, 1–5, 6–10, 11–15, and 16–20) and developed a randomly generated discrete distribution of when the actual land time would actually be relative to the plan. This variation is simply added to Wave 2, 3, or 4's planned arrival time (A1) and stored as A1', the actual time of arrival. Refer to Appendix A for variation distributions related to subsequent waves.

Anytime a flight is scheduled to takeoff (D2) in less than or equal to 60 minutes of the actual arrival time (A1'), a hot skid is required first followed by an aircrew swap before the next wave. In the rare event that the hot skids were occupied following completion of the hot brake check, the aircraft taxis back to the line for the aircrew swap and then returns to the hot skids for a second attempt. If, on the second attempt, the hot skids were still unavailable, the aircraft waits in queue until capacity exists. This model reflects reality in that a four-ship required to takeoff within the hour typically send the first two aircraft to the hot skids for fuel while the last two go to the line for an aircrew swap. Since the hot skid refueling process and the aircrew swap process take approximately the same amount of time, by the time the two aircraft in the line are complete with their aircrew swap and taxi back out to the hot skid area, the original two aircraft are refueling complete.

From the above narrative it should be clear the model continually assesses the probability that an aircraft will be able to takeoff within 20 minutes of the planned departure time. The discrete event checkpoints evaluating abort criteria include leaving the hot brake check, following an aircrew swap, prior to leaving final checks (applies only if the aircrew swap occurred *before* hot skid refueling), and prior to departing marshal for takeoff. At any point, the aircraft and other members of the flight event taxi back to their respective line and shutdown in order to preserve the aircraft for subsequent waves.

3. Operational Processes

When a flight lands consisting of two or more aircraft in the flight event, they breakup and operate as a single aircraft during the entire ground operations sequence. Then, if flying in a subsequent wave, the flight will rejoin as a single flight in the marshal process prior to takeoff. For this reason, anytime a member of a flight is required to abort (aircraft maintenance, inability to make scheduled takeoff time plus 20 minutes, or insufficient refueling resources), the model sends a signal to the other members of that same flight, regardless of location on the airfield, in order to maintain flight integrity.

The first process after landing is the hot brake check. Every aircraft landing at the airfield is required to receive a check of their brakes for overheating and have their canopy degaussed for static energy buildup. There are five hangars at the modeled airport and one of the hangars, Hangar 5, has two hot brake check areas for a total of six processes. All aircraft proceed to the hot brake check process nearest their squadron's hangar assignment. Upon arrival, each aircraft is required to wait in line until sufficient server capacity exists. The processing time is represented by a continuous probability distribution (triangular) with a minimum time of one minute, a maximum time of three minutes, and a mode of two minutes. According to our analysis, 65 percent of all arriving aircraft require the ordnance they are carrying to be de-armed (NAVAIR, 2012c). In these cases, one additional minute is added per aircraft to allow time for ordnance handling personnel to perform their duties.

Prior to departing the hot brake check process, the aircraft must know whether or not hot skid refueling is required. In all cases on the modeled airfield, the hot skids are entered from a location between the hot brake check process and the flight line. If an aircraft is scheduled to take off in 60 minutes or less (D2 minus A1'), a hot skid is automatically required. However, a hot skid may also be required if it is determined that there is insufficient fuel truck capacity within 30 minutes of the aircraft's planned takeoff time (D2 minus 30).

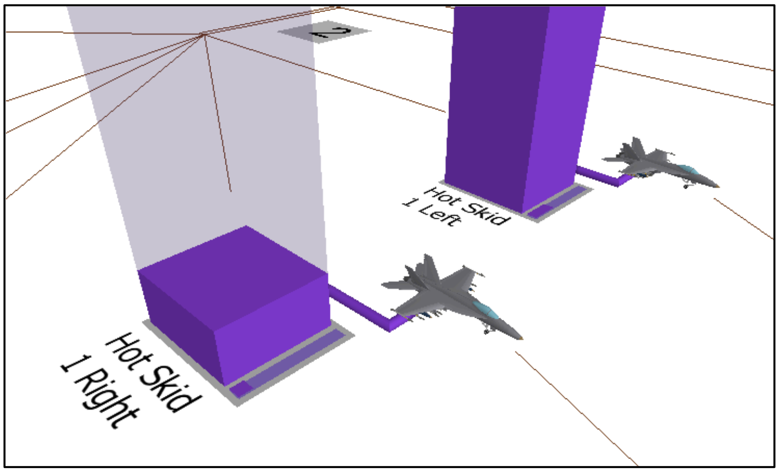

Figure 18. Hot Skid Refueling Operations (Simio screenshot)

The next process following the mandatory hot brake check is hot skid refueling for aircraft taking off in less than or equal to 60 minutes or for one of several other reasons highlighted earlier in this section. Each of the five hangars at the modeled airport has four hot skids, or lanes. Therefore, there are a total of 20 hot skids modeled in this implementation. The Simio screenshot provided in Figure 18 provides a visual representation of two aircraft receiving fuel from a hot skid with their engines online. This graphic was simplified by abstracting from significant manpower requirements and additional equipment and infrastructure—all of which are beyond the scope of the model. Important to note is servicing capacity in hot skid refueling is far greater than that of the fuel trucks. Furthermore, the hot skids never require a fill stand for replenishment as the trucks do.

Perhaps the most significant drawback of hot skid refueling is cost. Cost can be expressed in terms of time, fuel, and the additional aircraft maintenance from engine and avionics on time. In all cases, hot skid refueling arguably adds little value to operational effectiveness while squandering the resources of time, fuel, manpower, and aircraft wear and tear. The simulation developed for this MBA project was programmed to capture and accumulate all of these metrics.

Assuming sufficient capacity exists in the hot skid, the aircraft enters the first available lane. At this point, there is a one-minute delay to allow time for chocking, fuel cap removal, fuel hose attachment, and a safety assessment. Then, using a random, cumulative probability distribution unique to that specific aircraft type (F/A-18C, D, E, or F), the aircraft delays in the hot skid process equal to that amount, in gallons, divided by the fuel flow from the hot skids. Analysis was performed of over 4,300 successful refueling events involving fuel trucks, hot skids, local and transient aircraft, aircraft maintenance defueling, and various ground support equipment. Once paired down to only those successfully completed events involving hot skids, 531 remained spanning all four aircraft types (G. Blocker, personal communication, January 16, 2013). Refer to the supplementary information contained in Appendix A for more details related to fuel demand. Then, upon exit, an additional delay equal to one minute is required allowing time for fuel hose removal, fuel cap replacement, chock removal, and aircraft taxi out of the hot skid lane.

For those aircraft completing an aircrew swap prior to refueling by hot skid, a final check process is necessary. All aircraft meeting these criteria will delay for a period of three minutes allowing time for ground maintenance personnel to perform their required duties. Once complete with the short delay, the aircraft proceeds to marshal where it awaits the remaining members of its flight prior to takeoff.

If refueling by hot skid is not required, the aircraft is routed directly from the hot brake check process to the line. The model's line operations sub-model is depicted in Figure 19. This element of the model captures the post-flight check, aircrew swap, and engine shutdown processes, as well as seizure and release of truck refueling resources.

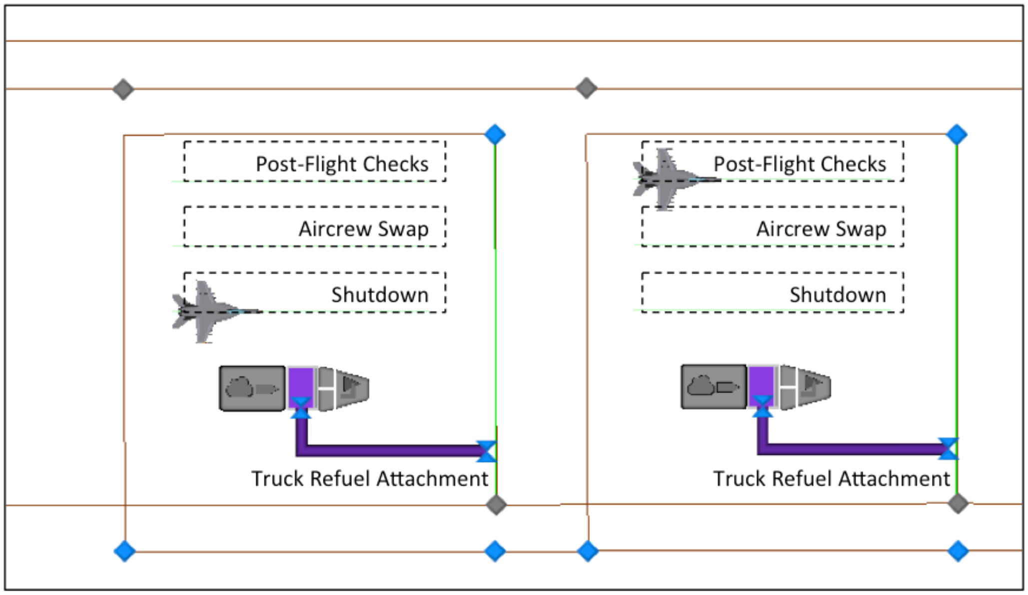

Figure 19. Line Operations

There are 188 total line operation sub-models located at various locations across the airport. In each case, every aircraft entering the line is required to complete post-flight checks. These checks capture the necessary steps to either prepare the aircraft for engine shutdown or prepare the aircraft for the next aircrew taking custody of the aircraft. Either way, those steps common to both the aircrew swap and to the engine shutdown processes are combined in this new process, called post-flight checks. The processing time is represented by a continuous probability distribution (triangular) with a minimum time of two minutes, a maximum time of four minutes, and a mode of three minutes.

Following an appropriate delay in post-flight checks, the aircraft is logically routed to either the aircrew swap or engine shutdown process. In order to enter the aircrew swap process, the aircraft must be scheduled for a subsequent wave, be required to launch in 60 minutes or less, and not be required to abort for one of several reasons highlighted in this chapter. The processing time is represented by a continuous probability distribution (triangular) with a minimum time of four minutes, a maximum time of six minutes, and a mode of five minutes. Once complete with the aircrew swap process, the aircraft either travels directly to marshal to await the other members of its flight, or to the hot skids for a second attempt at hot skid refueling.

The engine shutdown process is used anytime an aircraft is required to receive fuel via a fuel truck, the aircraft has more than 60 minutes before its next scheduled departure, the aircraft is entering the line from its last flight of the day, or the aircraft was flagged to abort for maintenance, or other. In each case, the processing time is the same. The processing time is represented by a continuous probability distribution (triangular) with a minimum time of two minutes, a maximum time of seven minutes, and a mode of three minutes. The maximum time seven minutes reflects the average amount of time spent talking to aircraft maintenance personnel during troubleshooting. However, given the positive (right) skew of this triangular distribution, the far more likely delay in the engine shutdown process is three minutes.

With the aircraft's engines now offline, the next process the request for fuel truck services from the dispatcher. There are two types of fuel trucks in this model, a 10,000 gallon truck and an 8,000 gallon truck. All experiments in this study were performed using eight 10,000 gallon and two 8,000 gallon fuel trucks. Future studies using our model may wish to manipulate the number of fuel trucks available in order to determine the optimal number of trucks a particular air installation should have in service to support daily flight operations. For our purposes, we have held this number constant at 10 fuel trucks in operation in each of 250 fly days per year. Again, the only time a fuel truck is requested is when the aircraft is required to fly in a subsequent wave. Aircraft landing from their final flight of the day do not request fuel services. Instead, station fuel services personnel refuel them after hours, which is beyond the scope of the model. Truck refueling services are not requested of the dispatcher until the aircraft is in the line with the engines off since the fuel truck cannot transfer any fuel until its engines are shutdown.

Using a random, cumulative probability distribution unique to that specific aircraft type (F/A-18C, D, E, or F), the aircraft retains the services of a fuel truck in time equal to its fuel demand, in gallons, divided by the fuel flow for the trucks. Of the 4,300 refueling events analyzed, 2,894 of them were used to construct the fuel distributions for all four aircraft types (G. Blocker, personal communication, January 16, 2013). Refer to the supplementary information contained in Appendix A for additional fuel distributional details. Upon completion of the truck refueling process, the aircraft will delay in the line until its next schedule departure. Furthermore, those aircraft that were required to use a hot skid due to insufficient truck servicing capacity also delay in the line with their engines off until their next scheduled departure.

The final ground process captured in the model is the truck refill process. The model assumes all fuel trucks are at maximum capacity when the simulation starts (when field operations commence). As each aircraft receives fuel, both the fuel truck's fuel remaining status as well as a global variable holding the total amount of fuel available for transfer across the airfield is updated. For simplification, a fuel truck is removed from service anytime its fuel remaining decreased below 2,500 gallons. If the now failed fuel truck had customers waiting in its queue for fuel, those aircraft are released and reassigned to other fuel trucks having capacity available. The time the truck is removed from service varies depending on how much fuel it had remaining. Since all fuel trucks are assumed to receive fuel at a rate of 475 gallons per minute, the maximum truck fuel capacity less fuel remaining divided by 475 is the length of time in delay minutes at the fill stand before returning to service (G. Blocker, personal communication, January 24, 2013).

4. Model Exit

There are several ways an aircraft exits the modeled system. The primary exit method is following engine shutdown and the end of the line operations process. This occurs whenever an aircraft has completed its final flight of the day or has been flagged to abort for one of several reasons (aircraft maintenance cancellation, failure to make scheduled takeoff time plus 20 minutes, insufficient refueling resources available, or other).

A second way an aircraft exits the system is following initial entry. Whenever the total number of aircraft created in a given hour exceeds the maximum number of aircraft specified in the time varying arrival table (Table 3), the aircraft is routed through a destruction process prior to any time or cost statistics being recorded. This ensures the model behaves in manner consistent with the intended level of operations.

The third and final method for managing aircraft in the system is through a destruction process following the secondary source. Recall the secondary source is responsible for managing the timing for all aircraft flying in waves subsequent to the first. Because the time of their landing is determined during the model's run, there is a chance the number of aircraft arriving in a given hour from the secondary source exceeds the maximum allowable in accordance with the time varying arrival table. Therefore, the model has logic to capture this rare event, destroy an appropriate number of aircraft, and reassign flight leadership responsibilities whenever necessary.

5. Cost Drivers

There are numerous cost drivers in any airfield operation. Included therein are aircraft operating costs, material and parts support, military and contractor personnel, facilities, and utilities to name a few. This model is responsible for capturing the total amount of time an aircraft spends in the system with its engines online from aircraft touchdown to engine shutdown. Those simulation planning factors having the most significant fiscal impact on aircraft operations are fuel flow rate from hot skid refueling and truck refueling, ground turnaround timing policies forcing more hot skid refueling than necessary, and the mix of aircraft type at the host airfield.

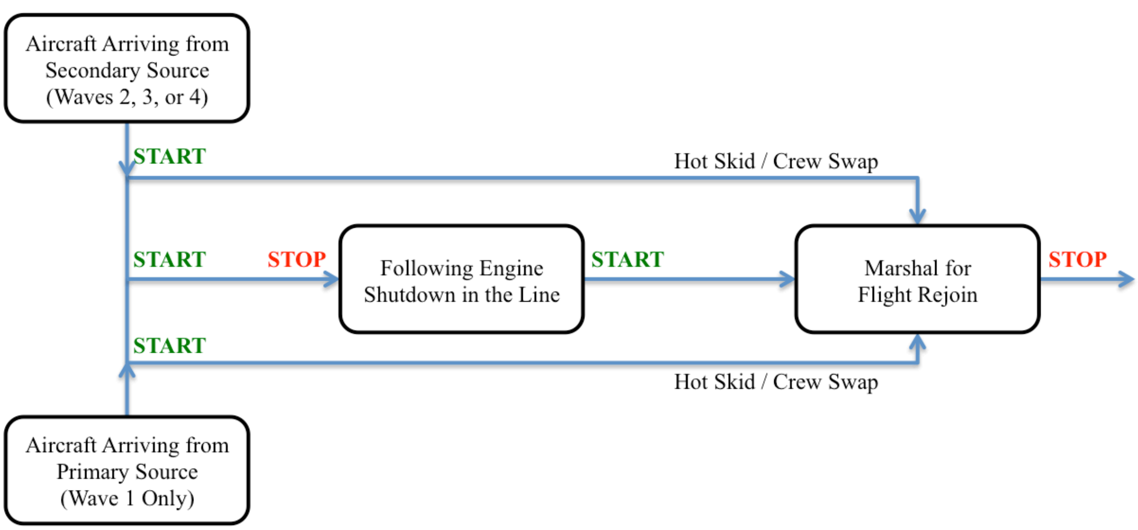

Figure 20. Aircraft Ground Idle Timing Logic

When an aircraft actually lands at the modeled airfield, the aircraft's ground idle clock is started and accumulates time until one of two events occur; one, the aircraft completes the engine shutdown process or, two, the aircraft takes off on a subsequent wave (Figure 20). With respect to the engine shutdown process, recall this will only occur when the aircraft has landed from its last flight of the day, has a ground turnaround time of greater than 60 minutes, is experiencing an aircraft maintenance problem, or has to abort its follow-on mission for one of several reasons previously noted. Furthermore, the model accumulates ground idle time first by aircraft type and then aggregates those amounts to determine the total time all aircraft spent at ground idle during a single day.

Time at ground idle is accumulating both in the queues and processing nodes of various ground processes as well as in the taxiways and line ramp areas between each of those processes. Since the model does not begin calculating statistics until the aircraft is clear of the runway on landing, the rates of travel are held constant across the entire airport in a network of nearly 1,700 paths and connectors. Since all aircraft entering the system are required to land on one of two runways, statistics do not start recording until entering Taxiway Alpha (Hangar 2) or Bravo (Hangar 1, 3, 4, or 5) from Runway 32L or Taxiway Foxtrot (all hangars) from Runway 32R. All aircraft then travel at a rate of 10 miles per hour to their destination while the fuel trucks at five miles per hour. Although aircraft and trucks can travel as fast as 15 miles per hour when on the taxiway, it is assumed for the purposes of the model that the average speed between taxiway and line ramp is 10 and 5 miles per hour respectively.

The next cost driver is the rate at which fuel is transferred from the hot skids and fuel trucks as well as the rate of refill for the fuel trucks when necessary. Since the rate of fuel flow determines time, and time determines both fuel and aircraft operating cost, it was very important that the model utilize the correct fuel flow rate. According to the NAS Lemoore Fuel Facilities Manager, fuel flow from both the fuel truck and the hot skids is nearly the same (G. Blocker, personal communication, January 24, 2013). The aircraft's ability to receive fuel in its external fuel tanks is the limiting factor. This model assumes that all aircraft are configured with a single external fuel tank. For this tank, the flow rate of fuel is slowed to approximately 120 gallons per minute (gpm) when filling to minimize the risks of damage to external fuel tank components. The internal fuel tanks, however, can receive fuel at a rate of 200 gpm. Since the external fuel capacity represents approximately 20 percent of total aircraft fuel capacity, a weighted average of 185 gpm is utilized in fuel transferred to aircraft in the model regardless of aircraft type or refueling source. The fuel trucks, on the other hand, refill at a fill stand (hot skid) using a fuel flow transfer rate between 450 and 500 gpm (G. Blocker, personal communication, January 24, 2013). For the purposes of this model, we used the median fuel flow rate of 475 gpm in calculating the amount of time necessary to refill a truck after reaching a state below 2,500 gallons remaining.

Another cost driver is aircraft type. According to the respective aircraft's NATOPS Flight Manual, the internal fuel capacity of an F/A-18C is 10,810 pounds (1,590 gallons) while an F/A-18E is 14,700 (2,160 gallons) (CNO, 2011a, 2012b). This equates to a 26 percent larger internal fuel capacity in the F/A-18E over the C-variant. In terms of time spent at ground idle in the hot skids, a minimum of three additional minutes over the F/A-18C is required at an average cost of $100.14 per minute in maintenance related costs and $12.83 in fuel (M. Angelopoulos, personal communication, January 30, 2013; DLA, 2012). This rule of thumb abstracts from the time spent refilling the E-variant's external fuel tank at 120 gpm, which is 33 percent larger than the C's external fuel tank (CNO, 2011a, 2012a). The cumulative fuel distributions by aircraft type are introduced in this section as Figures 21 and 22 representative of the F/A-18E. Refer to Appendix A for the remaining fuel distributions, details, and analysis of the over 4,300 actual refueling events throughout August 2012 (G. Blocker, personal communication, January 16, 2013).

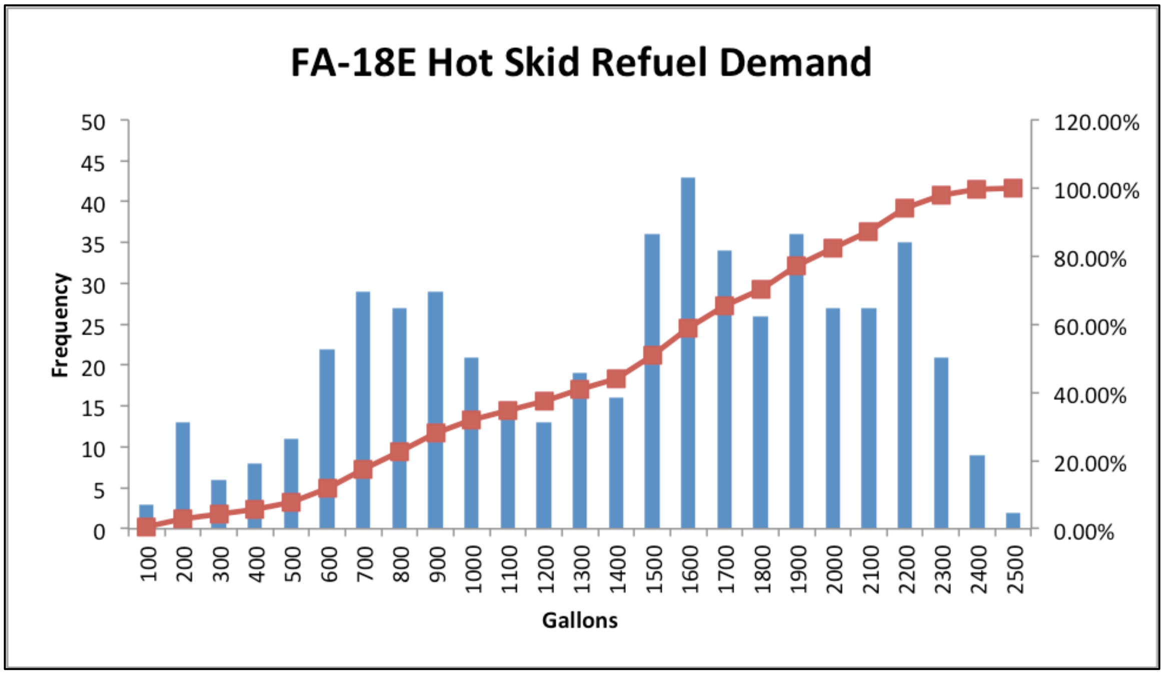

Figure 21. F/A-18E Hot Skid Refuel Demand

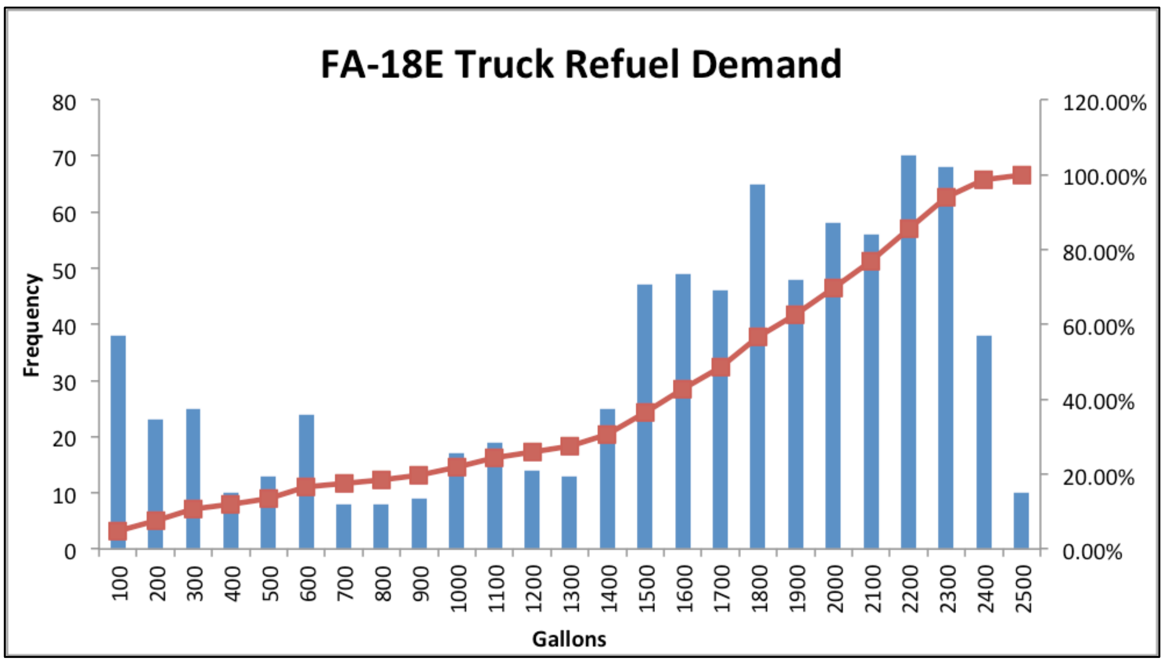

Figure 22. F/A-18E Truck Refuel Demand

The final cost driver evaluated by the model is the length of time a squadron uses as a planning factor for turning an aircraft around between two flight events. Each planned daily flight schedule of 16 squadrons spanning 21 fly days were analyzed during August 2012 and are summarized in Figure 23. Of the more than 2,600 flight events during the month, 539 launched and recovered during the day from 0800 to 1759 (T. Atkins, personal communication, January 15, 2013). The bi-modal frequency distribution depicted in Figure 23 highlights the systemic problem associated with the current refueling policy. Establishing a sound ground turnaround policy based on data, risk, cost, and operational readiness has the most significant impact on the post-flight gallons of fuel consumed and aircraft operating costs.

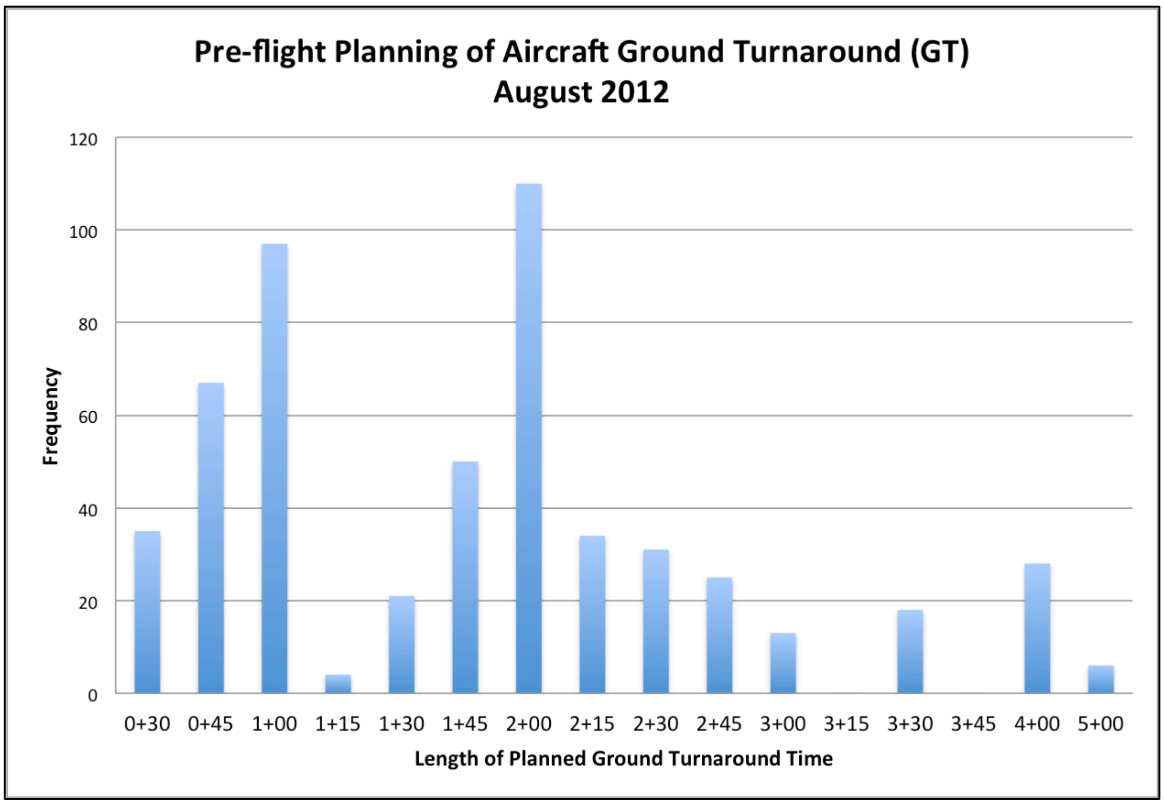

Figure 23. Pre-flight Planning of Aircraft Ground Turnaround Time

Most of the savings potential revealed in this MBA report stems from the model's output from one of four ground turnaround policies. The first reflects the baseline, or status quo, and is how the airfield was operating during August. During the time window of 0800 to 1759, 36.9 percent of all flight events involving subsequent waves planned for a ground turnaround time of 60 minutes or less (T. Atkins, personal communication, January 15, 2013). The second reflects an extreme in the opposite direction where only those missions requiring the use of a hot skid would be allowed to plan their flight schedules for it. Our research suggests that, with few exceptions, only 6.5 percent of all missions involving field carrier landing practice (FCLP) actually required the use of hot skid refueling (NAVAIR, 2012c). The third and fourth ground turnaround policies analyzed using the model's flexible programming ability were intermediate thresholds at 20 percent and 10 percent of all flights planned having ground turnaround of 60 minutes or less between flight events.

IV. ANALYSIS AND FINDINGS

A. EXPERIMENT OVERVIEW

From the evidence presented in government, commercial, and academic reports in this MBA project, Naval Aviation must evaluate their longstanding business processes for currency and relevancy. Failure to advance operational policies in the current fiscal environment, and tailor to our aircraft procurement strategy may hinder the Navy's ability to optimize the use of their scarce resources. According to Vice Admiral Myers (former Commander, Naval Air Forces), energy management is now an operational and strategic imperative (Myers, 2011). This section communicates the results of this project in terms of gallons of fuel conserved and total aircraft cost (maintenance and fuel) avoided by accepting or rejecting various policy inputs to the model.

The analysis in this project was made possible through discrete event simulation using the Simio software suite. This suite enabled the creation of a dynamic, three-dimensional, animated simulation of NAS Lemoore ground operations during August 2012. All aircraft, refueling resources (fuel trucks and hot skids), and post-flight operational processes have their own custom behavior that respond to events at both the system level and each other. Refer to Chapter III, as well as Appendix A, for a detailed functional specification of the model.

While a Navy-wide aviation model would provide a good tool for top-level decision makers, a tool focusing on aircraft with the highest fuel burn rate is most efficient. The F/A-18 Hornet and Super Hornet cost an average of $113 (FY12) per minute to operate on the ground during post-flight operations (M. Angelopoulos, personal communication, January 30, 2013). The goal of any policy recommendation from this study is to decrease the amount of time an aircraft spends on the ground with engines online without any impact to operational effectiveness, readiness, or safety. The results and findings in this chapter can be applied in a wide range of systems and military organizations, as the concepts of demand management are not unique to Naval Aviation.

Representing NAS Lemoore's runways as a multiple-server, aircraft arrive according to a time varying arrival rate per hour. As aircraft arrive, each proceeds through several different servers or stations in turn (hot brake checks, hot skids, aircrew swap, engine shutdown, and many others), and might have to wait in one or more queues for processing. In most cases, when a server finishes processing an aircraft, the next aircraft in queue is selected according to first in, first out principles. This dynamic interface between aircraft and model processes occur in approximately 100 aircraft per day between the hour of 0900 and 1759. Then, the model is replicated 250 times (simulating the number of fly days per year) using a random number generator to increase confidence in the annual result.

B. SLOT MANAGEMENT EXPERIMENTS

1. Question

What impact would decreasing variation in aircraft arrival rate per hour have on gallons of fuel consumed during post-flight ground operations?

2. Setup

Representing NAS Lemoore's runways as a single server, aircraft arrive according to a non-stationary, Poisson distribution. The average number of aircraft arrivals in any hour of the relevant timeframe is 11.9, or 12 in terms of whole aircraft. A critical concept in understanding this section is standard deviation. Standard deviation (represented by the letter "s") is simply how much, on average, the number of aircraft arrivals per hour differs from the average number of aircraft arrivals during the period of 0900 to 1759. Stated another way, standard deviation measures the spread of each hour's number of arrivals around the average over the entire period. Refer to Figure 24 for a graphical depiction of standard deviation about the mean of arriving aircraft per hour in three of 12 planned experiment levels. This data comes from actual flight data recorded during August 2012. With each incremental decrease in the standard deviation of the mean, the number of aircraft arrivals per hour approaches the average.

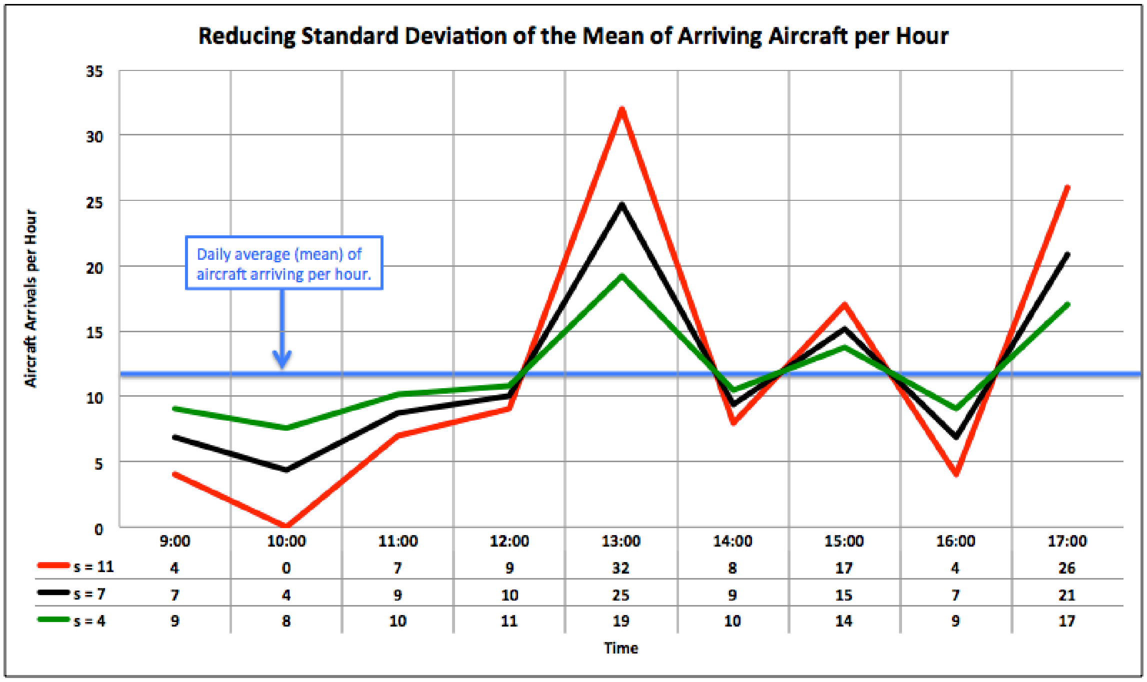

Figure 24. Reducing Standard Deviation of the Mean of Arriving Aircraft per Hour

Figure 25 depicts our analysis of historical flight schedules from August 2012. The data captured in this figure is based entirely on flight schedule *plans*. The *actual*, executed, flight schedules are not reflected. The average, most common, standard deviation of the mean of arriving aircraft per hour in August was 7.0.

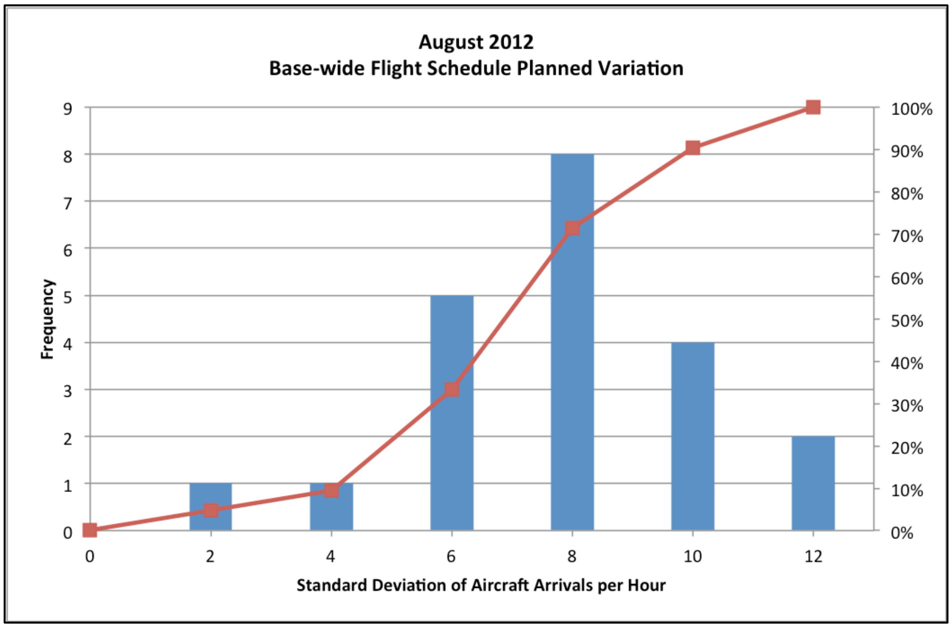

Figure 25. Planned Base-wide Flight Schedule Variation (August 2012)

All aircraft and model properties, states, and parameters were held constant during the slot management experiments with the exception of the number of aircraft arrivals per hour. Tables 6 and 7 depict the inputs to the model in each of 12 different experiments representing 12 different standard deviations of the mean of arriving aircraft per hour. Table 7 shows how closely the model is able to simulate the data input over the course of one year (250 replications). Of note, the term “Hour 1” is akin to the period of time from 0800 to 0859.

Model Input Table												
Std Dev	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
8:00	0	0	0	0	0	0	0	0	0	0	0	0
9:00	4	5	5	6	7	8	8	9	10	10	11	12
10:00	0	1	2	3	4	5	6	8	9	10	11	12
11:00	7	7	8	8	9	9	10	10	11	11	11	12
12:00	9	9	10	10	10	10	11	11	11	11	12	12
13:00	32	30	28	27	25	23	21	19	17	16	14	12
14:00	8	8	9	9	9	10	10	10	11	11	12	12
15:00	17	17	16	16	15	15	14	14	13	13	12	12
16:00	4	5	5	6	7	8	8	9	10	10	11	12
17:00	26	25	23	22	21	20	18	17	16	14	13	12
s	11	10	9	8	7	6	5	4	3	2	1	0
x-bar	12	12	12	12	12	12	12	12	12	12	12	12
sorties	107	107	107	107	107	107	107	107	107	107	107	107

Table 6. Slot Management Model Input Table

Hourly Aircraft Arrival Table													
		s = 11	**s = 10**	**s = 9**	**s = 8**	**s = 7**	**s = 6**	**s = 5**	**s = 4**	**s = 3**	**s = 2**	**s = 1**	**s = 0**
Model Input	Hour 1	-	-	-	-	-	-	-	-	-	-	-	-
	Hour 2	4.00	4.72	5.43	6.15	6.87	7.59	8.30	9.02	9.74	10.45	11.17	11.89
	Hour 3	-	1.08	2.16	3.24	4.32	5.40	6.48	7.57	8.65	9.73	10.81	11.89
	Hour 4	7.00	7.44	7.89	8.33	8.78	9.22	9.67	10.11	10.56	11.00	11.44	11.89
	Hour 5	9.00	9.26	9.53	9.79	10.05	10.31	10.58	10.84	11.10	11.36	11.63	11.89
	Hour 6	32.00	30.17	28.34	26.52	24.69	22.86	21.03	19.20	17.37	15.55	13.72	11.89
	Hour 7	8.00	8.35	8.71	9.06	9.41	9.77	10.12	10.47	10.83	11.18	11.54	11.89
	Hour 8	17.00	16.54	16.07	15.61	15.14	14.68	14.21	13.75	13.28	12.82	12.35	11.89
	Hour 9	4.00	4.72	5.43	6.15	6.87	7.59	8.30	9.02	9.74	10.45	11.17	11.89
	Hour 10	26.00	24.72	23.43	22.15	20.87	19.59	18.30	17.02	15.74	14.45	13.17	11.89
Model Output	Hour 1	-	-	-	-	-	-	-	-	-	-	-	-
	Hour 2	3.21	4.24	4.22	5.33	6.36	7.40	7.41	8.45	9.49	9.47	10.40	11.59
	Hour 3	-	0.07	1.22	2.18	3.22	4.25	5.28	7.42	8.42	9.34	10.41	11.41
	Hour 4	6.33	6.31	7.30	7.32	8.43	8.38	9.41	9.43	10.37	10.37	10.46	11.44
	Hour 5	8.43	8.39	9.58	9.52	9.45	9.53	10.50	10.62	10.60	10.52	11.61	11.60
	Hour 6	31.65	29.77	27.74	26.74	24.76	22.78	20.63	18.70	16.71	15.67	13.76	11.67
	Hour 7	7.46	7.56	8.55	8.52	8.52	9.55	9.61	9.70	10.71	10.76	11.71	11.71
	Hour 8	16.63	16.68	15.75	15.73	14.67	14.68	13.67	13.73	12.64	12.63	11.82	11.70
	Hour 9	10.79	9.65	10.23	10.02	9.79	9.92	9.34	9.54	10.09	10.03	10.81	11.67
	Hour 10	25.80	24.89	22.85	21.80	20.81	19.82	17.73	16.72	15.76	13.66	12.79	11.71

Table 7. Slot Management Time Varying Arrival Table (Input Versus Output)

Of the variables held constant, the most significant cost driver was the amount of time each aircraft had for servicing in between events. In each of the slot management experiments, no aircraft was allowed to have a ground turnaround less than or equal to 60 minutes in length. Although this does not reflect the real world, it does prevent the hot skids from absorbing inefficiencies in the total system. Isolating ground refueling to fuel trucks only, by virtue of scheduling aircraft ground turnaround greater than 60 minutes, ensured the effects of reducing standard deviation of the mean of arriving aircraft per hour could be studied. Figure 26 depicts the ground turnaround policy for the slot management experiments and the probability of each ground turn duration expressed in hours and minutes.

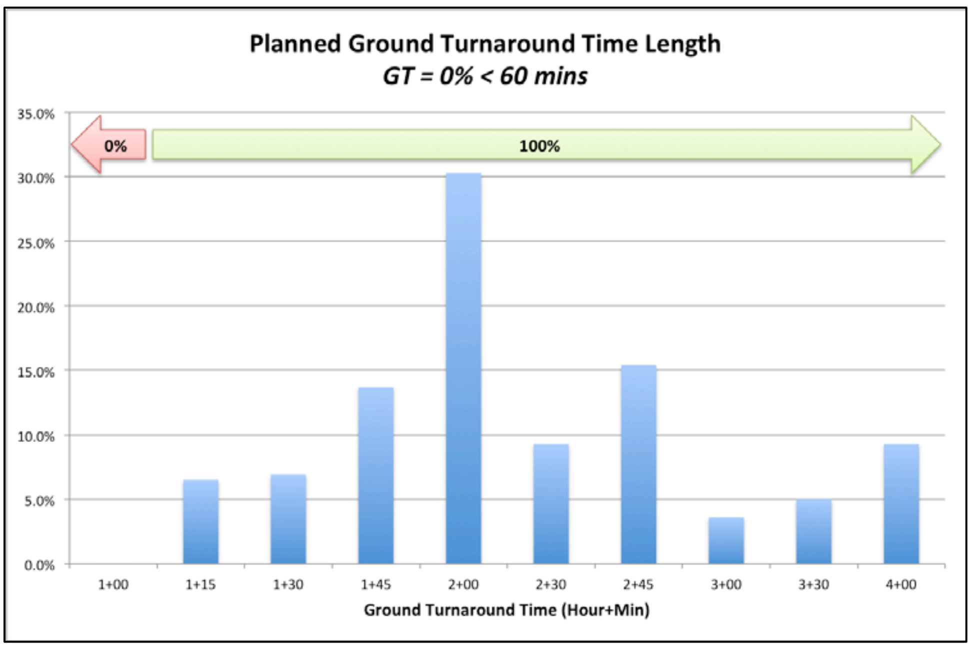

Figure 26. Slot Management Planned Ground Turnaround Time

The remaining assumptions input to the model involved ground refueling resources. Of all of the fuel trucks contracted and leased to NAS Lemoore, it is assumed the number of fuel trucks in service is 10. Of the 10 trucks, eight have a 10,000 gallon fuel capacity and two an 8,000 gallon fuel capacity. Furthermore, these fuel trucks are assumed to be 100 percent reliable in that, as trucks attrite for maintenance problems during the course of the day, each truck is easily replaceable having no impact on the squadron's flight schedule. Hot skids, on the other hand, were restricted to zero during preflight planning of the squadron's schedule by ensuring all ground turnarounds were planned in excess of 60 minutes (Figure 26). However, in the course of the model run, if the demand for fuel trucks becomes too great, aircraft are permitted to cycle through the hot skids in order to make their next scheduled departure.

An additional concept necessary in understanding what drives cost in flight schedule execution is the difference between inherent and systemic, or network, variation. Figure 27 depicts the actual landing time distribution about the planned landing time (T. Atkins, personal communication, January 15, 2013; NAVAIR, 2012b). Although the mode of arriving aircraft is at the prescribed landing time, approximately 20 percent of aircraft land early and 45 percent land late from the planned time. The variation noted in Figure 27 is from the first arrival of the day and reflects the inherent variation aircraft arrivals per hour. All subsequent waves are impacted from the performance of the first arriving wave. In this chart, the average land time is almost one minute late with a standard deviation of 12.8 minutes. This means that 68 percent of all landings fall in the range of plus or minus 13 minutes of planned.

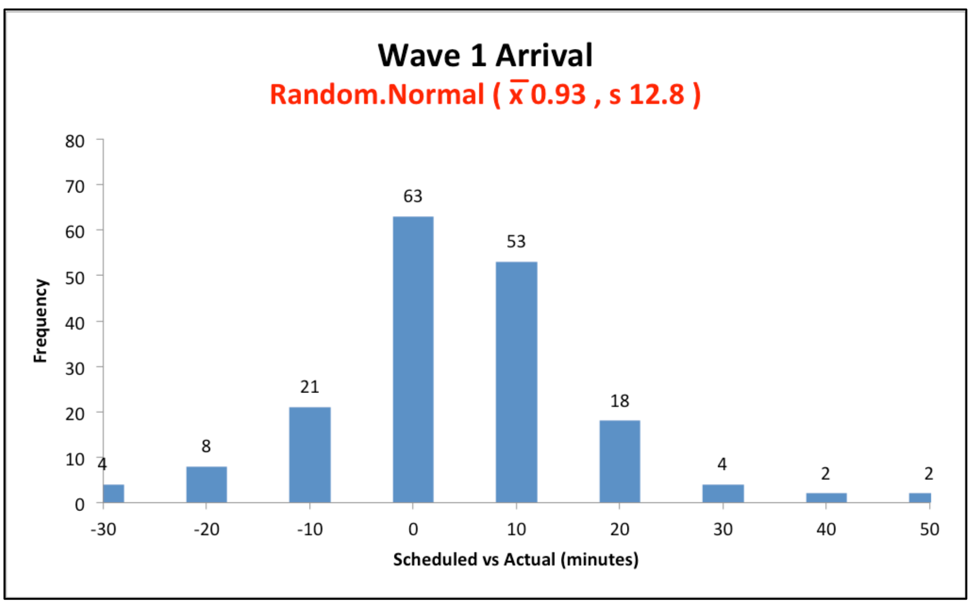

Figure 27. Wave 1 Arrival Variation

Inherent variation in the aircrew's ability to execute the flight schedule as written has an exponentially negative impact on flight events. Contrasting Figure 28 with Figure 29 using actual flight data from August 2012, the concept of systemic variation is articulated best. Observe the tendency to land late more than 35 percent of the time despite taking off exactly as prescribed (Figure 28). Then, in Figure 29, launching between 11 and 15 minutes late leads to a late arrival in more than 70 percent of all cases (T. Atkins, personal communication, January 15, 2013; NAVAIR, 2012b). Refer to Appendix A for a more comprehensive discussion of the network effects of variation in aircraft arrivals.

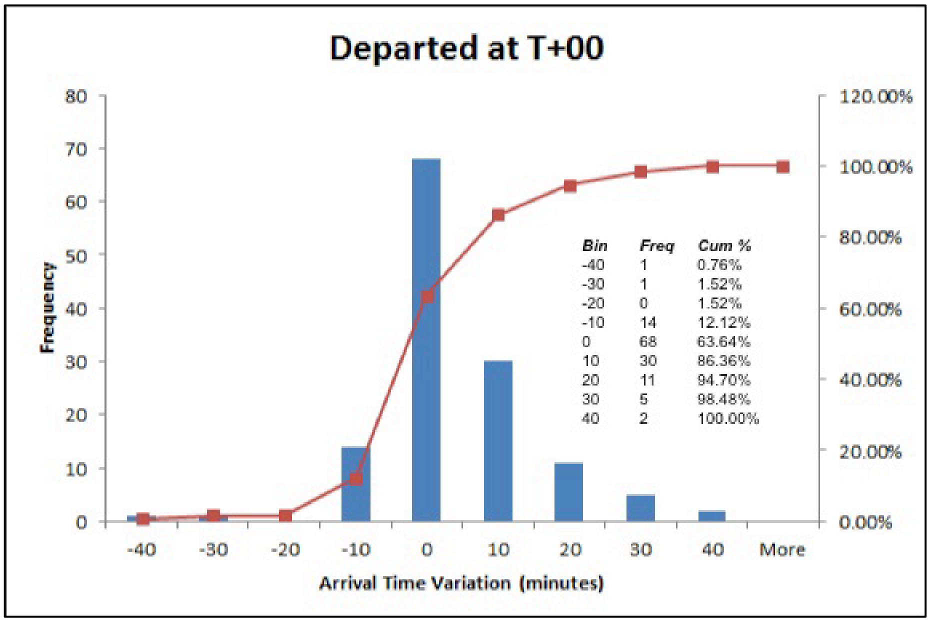

Figure 28. Arrival Variation When Launching on Time

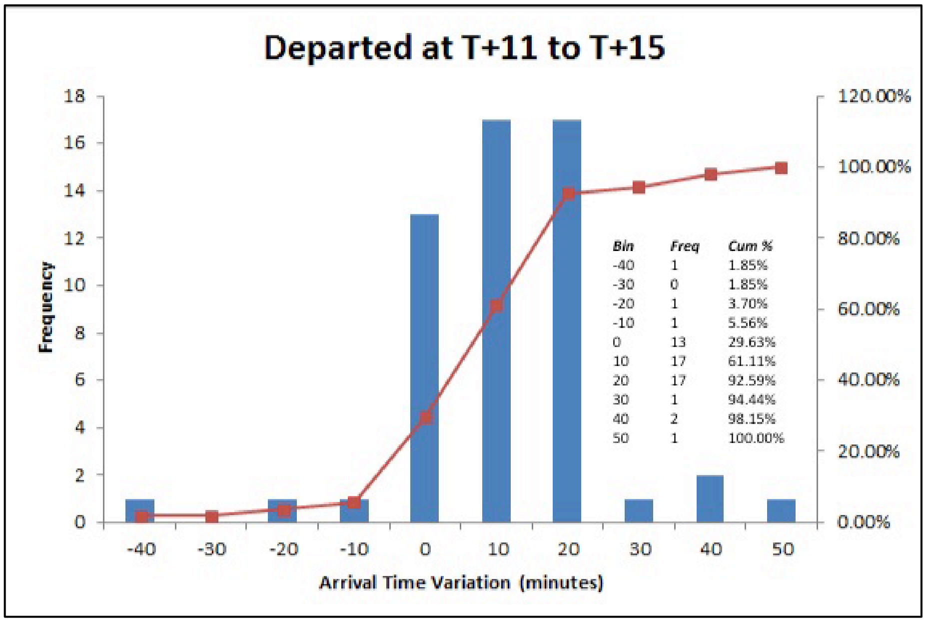

Figure 29. Arrival Variation When Launching 11–15 Minutes Late

3. Results

As variation in the arrival of aircraft per hour is reduced through 12 different levels (expressed as standard deviations of the mean), the average time an aircraft spent on the ground at idle was also reduced. When the standard deviation of the mean was 11, worst-case scenario observed, the average time an aircraft was online from touchdown to engine shutdown was 21.46 minutes. At the most commonly observed level, s = 7, the average time was 20.87 minutes. Theoretically, given the constraints of the model, the best average idle time is 20.24 minutes per aircraft. Table 8 and Figure 30 reflects the model’s output and summarizes the impact reducing variation in the arrival of aircraft has on ground idle operations after landing. Of note, below a standard deviation of the mean of 3, there is insufficient evidence to suggest a benefit of reducing variation further.

Data per Aircraft	Average Minutes at Idle per Aircraft	Std Dev	Sample Size	Margin of Error	Marginal Diff in Minutes
s=0	20.24	0.8386	236	0.1076	(0.00)
s=1	20.24	0.8327	239	0.1061	0.09
s=2	20.33	0.8656	239	0.1103	(0.06)
s=3	20.27	0.8510	205	0.1172	0.14
s=4	20.41	0.8403	250	0.1047	0.14
s=5	20.55	0.9196	232	0.1190	0.11
s=6	20.66	0.9069	250	0.1130	0.21
s=7	20.87	1.0016	216	0.1343	0.11
s=8	20.98	1.0552	250	0.1314	0.12
s=9	21.11	1.0431	228	0.1361	0.31
s=10	21.41	1.0742	242	0.1360	0.04
s=11	21.46	1.2284	230	0.1596	0

Average Number of Sorties per Day	105.7	sorties
Annual Number of Fly Days	250	days
Average Aircraft Fuel Burn at Idle	3.42	gallons

Table 8. Slot Management Variation Impacts on Time per Aircraft

Figure 30 depicts an average decrease of more than one minute per aircraft by implementing a slot management policy reducing variation in aircraft arrivals from s = 7, most common, to s = 4, recommended.

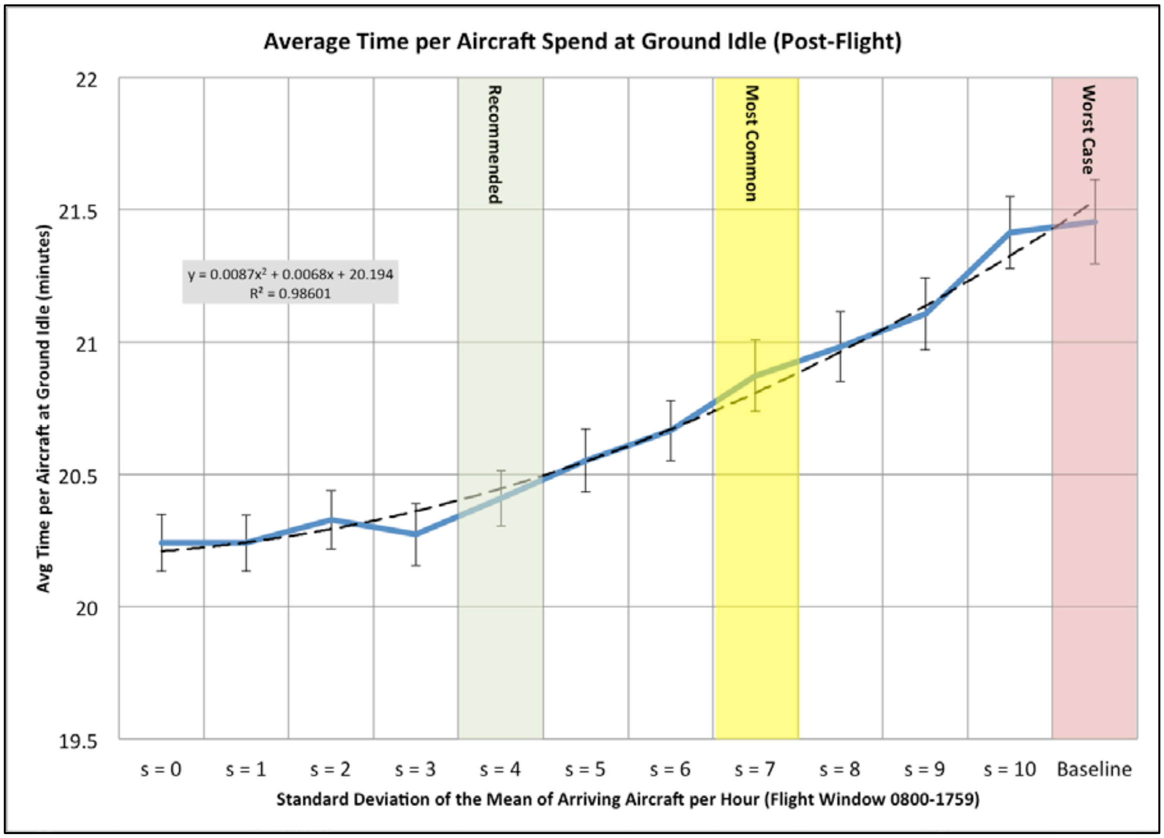

Figure 30. Slot Management Variation Impacts on Time per Aircraft

Table 9, as well as Figures 31 and 32, summarize the incremental change in gallons of fuel consumed per year at the modeled airport. Each step, from bottom to top, represents the amount of fuel and cost, on the margin, that can be avoided by adopting a slot management policy forcing a reduction in arrival variation.

Data per Aircraft	Annual Incremental Gallons	Fuel Cost	Maintenance Cost	Total Cost
s=0	(2)	$ (7)	$ (50)	$ (57)
s=1	7,935	$ 29,756	$ 202,625	$ 232,381
s=2	(5,047)	$ (18,925)	$ (128,875)	$ (147,801)
s=3	12,422	$ 46,582	$ 317,204	$ 363,785
s=4	12,874	$ 48,278	$ 328,754	$ 377,032
s=5	10,109	$ 37,908	$ 258,141	$ 296,049
s=6	18,762	$ 70,359	$ 479,119	$ 549,478
s=7	9,930	$ 37,236	$ 253,562	$ 290,798
s=8	11,230	$ 42,112	$ 286,767	$ 328,879
s=9	27,831	$ 104,366	$ 710,696	$ 815,062
s=10	3,668	$ 13,756	$ 93,671	$ 107,427
s=11	0	0	0	0

Table 9. Slot Management Variation Impacts on Incremental Metrics

Table 10, as well as Figures 31 and 32, summarize the cumulative change in gallons of fuel consumed per year at the modeled airport. Each step, from bottom to top, represents the amount of fuel and cost, in cumulative terms, which can be avoided by adopting a slot management policy forcing a reduction in arrival variation.

Data per Aircraft	Annual Cumulative Gallons	Fuel Cost	Maintenance Cost	Total Cost
s=0	109,712	$ 411,420	$ 2,801,614	$ 3,213,034
s=1	109,714	$ 411,427	$ 2,801,663	$ 3,213,091
s=2	101,779	$ 381,672	$ 2,599,038	$ 2,980,710
s=3	106,826	$ 400,597	$ 2,727,913	$ 3,128,511
s=4	94,404	$ 354,015	$ 2,410,710	$ 2,764,725
s=5	81,530	$ 305,738	$ 2,081,956	$ 2,387,693
s=6	71,421	$ 267,829	$ 1,823,815	$ 2,091,644
s=7	52,659	$ 197,470	$ 1,344,696	$ 1,542,166
s=8	42,729	$ 160,234	$ 1,091,134	$ 1,251,368
s=9	31,499	$ 118,122	$ 804,367	$ 922,489
s=10	3,668	$ 13,756	$ 93,671	$ 107,427
s=11	0	0	0	0

Table 10. Slot Management Variation Impacts on Cumulative Metrics

As standard deviation of the mean of arriving aircraft per hour is incrementally reduced from 7 to 4 there is a substantial fuel and cost avoidance opportunity. Figure 31 depicts the change (decrease) in gallons of fuel consumed per year by reducing variation in arrivals. Our research suggests a savings of 41,745 gallons of fuel is realized by implementing control activities capable of reducing the standard deviation of the mean of arriving aircraft per hour from 7, the most common case in August 2012, to 4. Of note, below a standard deviation of the mean of 3, there is insufficient evidence to suggest a benefit of reducing variation further.

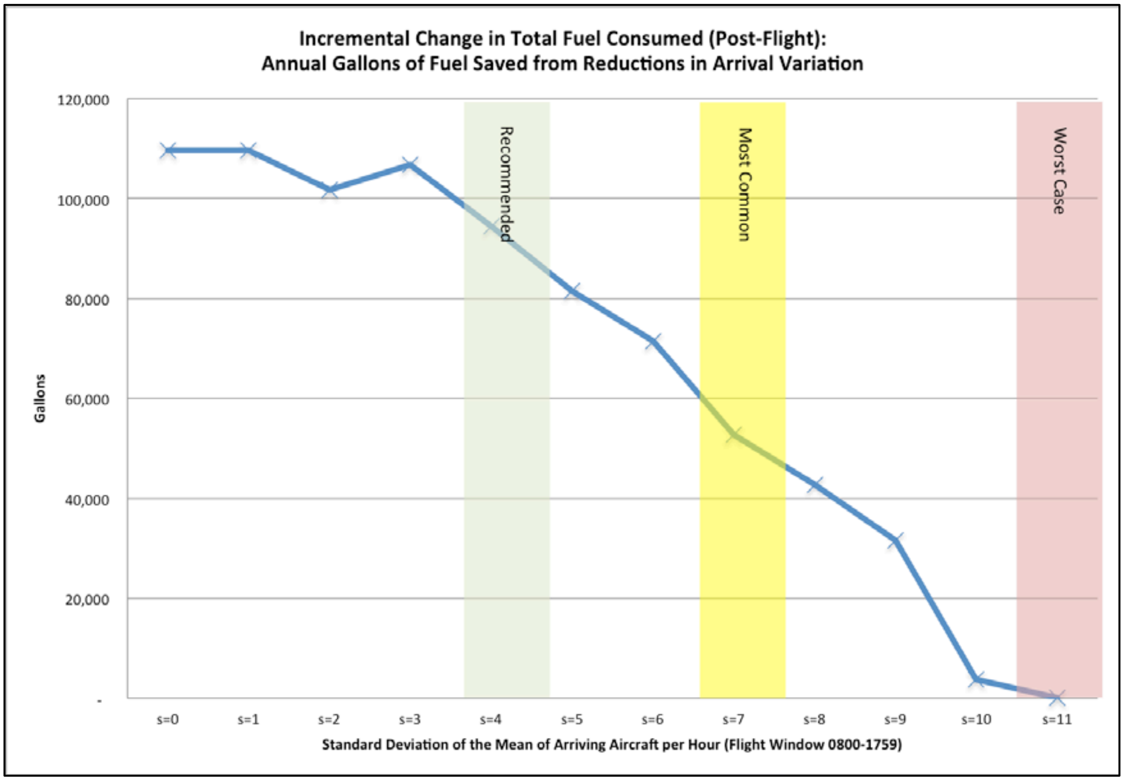

Figure 31. Incremental Change in Total Fuel Consumed (Slot Management Policy)

Figure 32 depicts the change (decrease) in total aircraft operating cost per year by reducing variation in arrivals. Using the worst-case standard deviation observed during August as the base, aircraft maintenance (AVDLR, consumables, and contracts) and fuel costs are avoided simply by balancing the arrival rate of aircraft. Our research suggests a savings of $1,222,559 (FY12) are possible by implementing control activities capable of reducing the standard deviation of the mean of arriving aircraft per hour from 7, the most common case in August 2012, to 4.

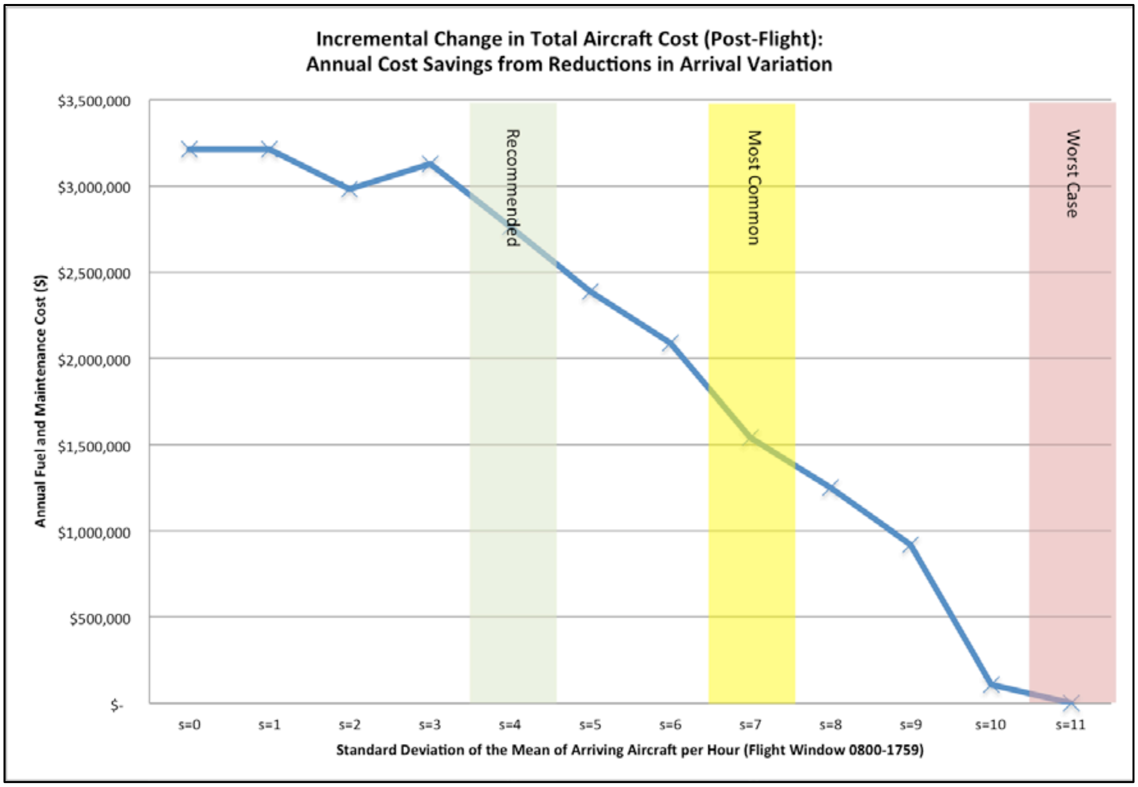

Figure 32. Incremental Change in Total Aircraft Operating Cost (Slot Management Policy)

Introducing a slot management policy to any tactical air (TACAIR) base would likely yield other, unintended, benefits. Table 11 shows one such advantage for the average time it takes a fuel truck to complete servicing once requested. As variation about the mean of arriving aircraft is reduced, so too is the average response time from requisition to completion. Furthermore, the maximum observed wait time by reducing the variation in aircraft arrival rate from 7 to 4 was reduced from 42.6 to 37.1 minutes.

Truck Resourcing Data								
Experiment	Mean Response	Std Dev	Sample Size	Margin of Error	Max Wait Time	Truck in Use (Mins)	Utilization	Avg Svc per Acft
s=0	14.2	0.71	236	0.09	37.8	1,828.6	33.9%	17.50
s=1	14.2	0.72	239	0.09	32.0	1,776.3	32.9%	17.12
s=2	14.2	0.75	239	0.10	35.1	1,925.7	35.7%	18.80
s=3	14.3	0.73	205	0.10	32.7	1,845.0	34.2%	17.61
s=4	14.3	0.73	250	0.09	37.1	1,826.3	33.8%	17.51
s=5	14.4	0.78	232	0.10	36.7	1,792.5	33.2%	17.31
s=6	14.5	0.82	250	0.10	41.0	1,818.5	33.7%	17.10
s=7	14.6	0.87	216	0.12	42.6	1,869.3	34.6%	17.63
s=8	14.8	0.99	250	0.12	45.6	1,802.0	33.4%	16.82
s=9	14.9	0.14	228	0.02	44.7	1,797.4	33.3%	16.73
s=10	15.1	1.13	242	0.14	44.0	1,717.7	31.8%	15.97
s=11	15.4	1.27	230	0.17	47.0	1,804.3	33.4%	16.36

Table 11. Slot Management Variation Impacts on Fuel Truck Resourcing

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C. GROUND TURNAROUND TIMING EXPERIMENTS

1. Question

How much time between flight events should squadrons plan for when developing their daily flight schedule?

2. Setup

"Truck refueling should be used to the max extent practicable" (Myers, 2011). This quote by the former commander, Naval Air Forces, suggests he and his staff have completed a risk assessment and accepted challenges and opportunities in decreasing hot skid usage. Establishing a more concrete policy at the type wing level is now necessary given the squadron's inability to affect the desired paradigm shift unilaterally. If leadership is serious about cost-wise readiness, promulgating a ground turnaround or hot skid refueling policy is the next logical step.

This experiment follows a history of hot skid refueling studies spanning 33 years (NADC, 1980). Much progress has been made at NAS Lemoore from the days when A-7 Corsair's were hot refueled 85 percent of the time. With each new aircraft that joins the Fleet, commanders must validate existing polices for their appropriateness. The Navy's strike-fighter complement is once again in transition to the newer F/A-18EF Super Hornet. Although NAS Lemoore is nearing completion, NAS Oceana and NAS Whidbey Island may seriously consider the recommendations contained in this report, as they are both earlier in the transition.

The following experiments represent four possible ground turnaround (GT) policies spanning the full spectrum of alternatives. In each case, the standard deviation of the mean of arriving aircraft per hour is held constant at 4. Furthermore, all aircraft and model properties, states, and parameters were held constant during each of the four GT policy options. In addition to holding variation in arrival rate constant, the number of fuel trucks in service as well as hot skid availability during the model run is unchanged from the slot management experiments.

Driving changes in gallons of fuel consumed and aircraft operating cost is the amount of time an aircraft has to turnaround between events. The calculation for this time is simply the difference between the time an aircraft lands until the time that same aircraft is scheduled to take off again. As GT decreases below 60 minutes, the hot skids are assumed to be the only viable refueling option (Figure 33). Conversely, as GT exceeds 60 minutes, there is assumed to be ample time to shut the engines down in the line and dispatch a fuel truck for refueling.

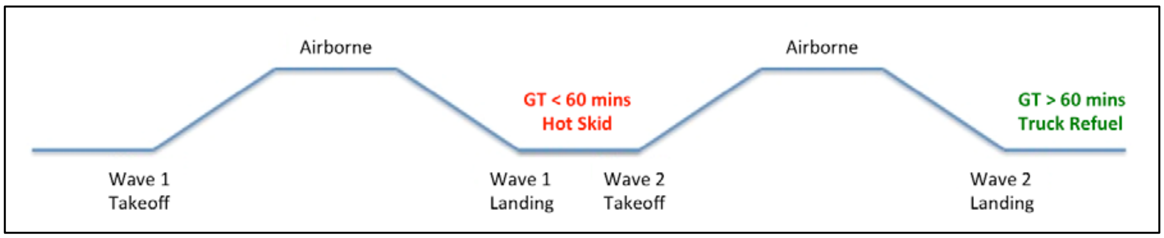


Figure 33. Flight Profile Relationships

The ground turnaround policy options in this section are addressed from a pre-flight planning perspective. The first experiment titled "GT Status Quo," places no restriction on the percentage of aircraft authorized a ground turnaround of less than or equal to 60 minutes. The next two scenarios further restrict the percentage of sorties scheduled with a ground turnaround 60 minutes or less to 20 percent and 10 percent respectively. The final scenario authorizes use of the hot skids for refueling only when absolutely necessary for the mission's success.

Every squadron flight schedule during August 2012 at NAS Lemoore was examined. From a planning perspective, the flow of aircraft from one event to the next was determined under the premise that each operational squadron would want to operate the least number of aircraft possible. For example, squadrons flowing a 4-ship followed by another 4-ship with a two hour ground turnaround in between would be counted as four aircraft planning to use the fuel trucks for post-flight refueling, not eight different aircraft. The planned refueling events considered relevant to this study were further restricted to only those flights that arrive during the period of 0800 and 1759 and were required to fly again in a subsequent wave. Recall that aircraft landing on their last flight of the day can receive fuel at any time prior to the next fly day and therefore are excluded from the allocation queue for fuel. The result of this analysis showed 199 flights planned a ground turnaround of 60 minutes or less during August while 340 were planned to be something greater (S. Cotta, personal communication, January 25, 2013). Figure 34 represents this fact and was used in establishing the ground turnaround distribution in the first scenario (GT Status Quo).

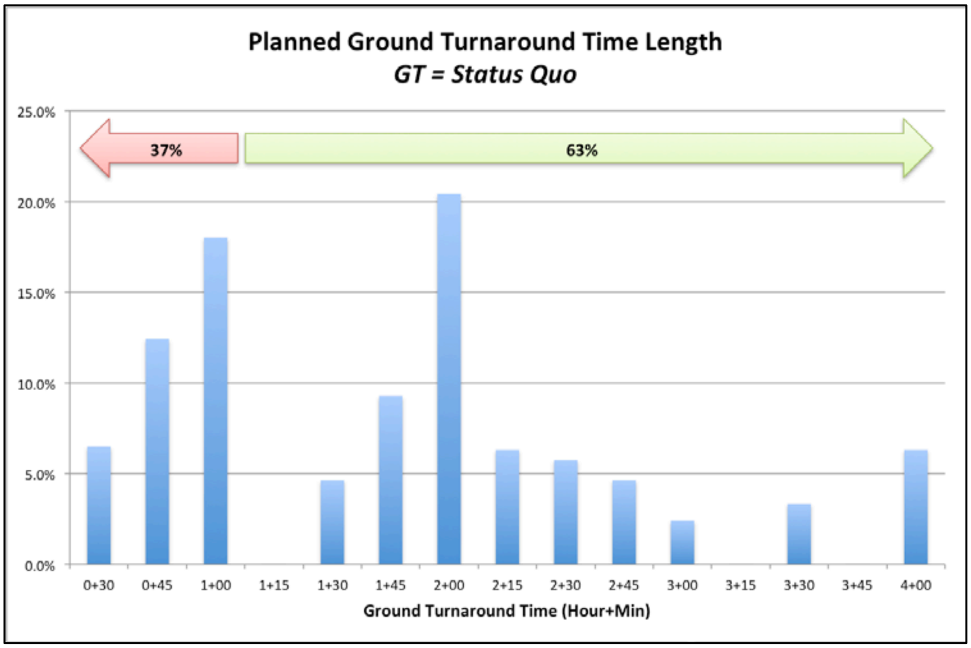


Figure 34. Planned Ground Turnaround Time (Status Quo)

Figures 35 and 36 represent the ground turnaround distributions used in the second and third scenarios respectively and are based on actual flight data that was recorded in August 2012.

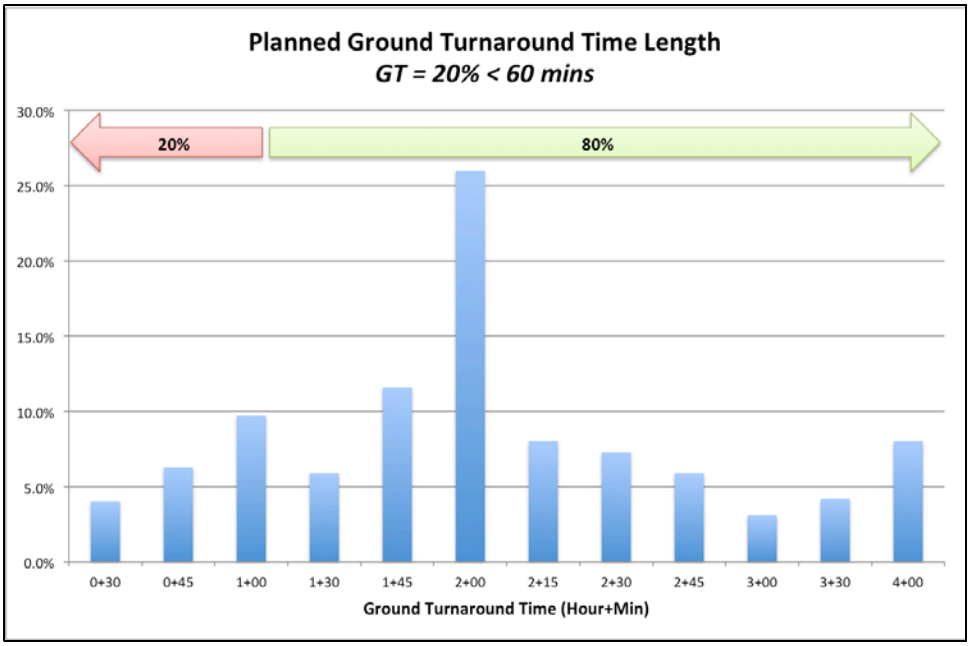


Figure 35. Planned Ground Turnaround Time (20% < 60 mins)

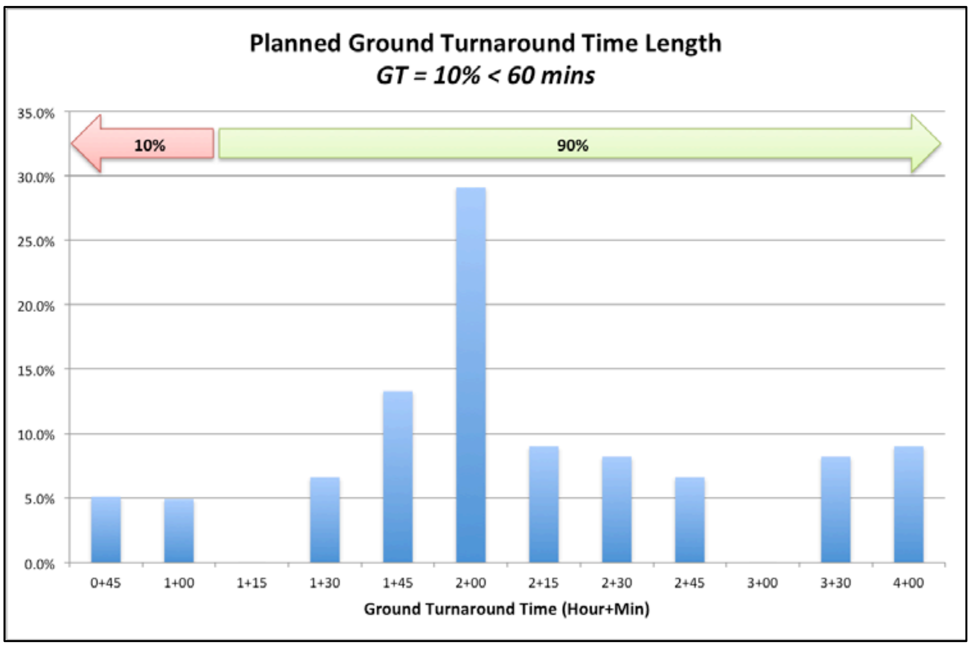


Figure 36. Planned Ground Turnaround Time (10% < 60 mins)

Of all the flights successfully flown and logged during August 2012, 6.5 percent of them had a Total Mission Requirement (TMR) code of "1A3" indicating Field Carrier Landing Practice (FCLP) (see Table 12) (NAVAIR, 2012c). FCLP is a special mission performed at the airfield itself and of typically very short duration, often less than 45 minutes. It would create a significant and senseless burden on squadron aircrew and maintenance personnel to shut the aircraft down following events of such a short duration. Therefore, this mission is considered by our study to require hot skid refueling.

For efficiency and operational effectiveness, the hot skids are necessary in support of the FCLP mission representing 6.5 percent of the total training continuum (Table 12). Figure 37 depicts a GT timing distribution supporting only FCLP missions using an aircraft turn of less than or equal to 60 minutes.

Flights Requiring Field Carrier Landing Practice (FCLP)					
TMR	F/A-18C	TMR	F/A-18E	TMR	F/A-18F
1A0	9	1A0	2	1A0	4
1A1	358	1A1	232	1A1	532
1A2	23	1A2	30	1A2	27
1A3	176	1A3	115	1A3	164
1A4	38	1A4	6	1A4	14
1A5	10	1A5	4	1A5	23
1A6	928	1A6	485	1A6	840
1A7	659	1A7	275	1A7	743
1A8	1	1A9	4	1A9	8
1A9	1	1B6	4	1B1	4
1B1	2	1B7	3	1B6	22
1B6	17	1C1	3	1B7	8
1B7	12	2J1	3	1C1	14
1C1	6	2J2	13	1C5	1
1F1	2	2K0	1	1F1	4
1I3	1	2K2	10	1G1	18
2J1	1	2K4	242	1G6	41
2J2	93	2K7	7	1G7	49
2K0	1	2K8	2	1G9	2
2K1	3	2K9	1	2J1	7
2K2	121	2L0	33	2J2	65
2K3	6	2L1	24	2K0	2
2K4	190	2L7	1	2K1	1
2K6	1	2L9	16	2K2	16
2L0	79	2Q4	8	2K4	204
2L1	6	2Q6	2	2K7	4
2L2	1	3S2	1	2L0	34
2L9	13		**1527**	2L1	16
2M6	2			2L3	1
2Q4	33			2L5	16
	2793			2L9	51
				2Q1	3
				2Q4	23
				2Q6	2
				3S2	1
					2964
6.3%	FCLP	7.5%	FCLP	5.5%	FCLP

Table 12. Flights Engaged in Field Carrier Landing Practice

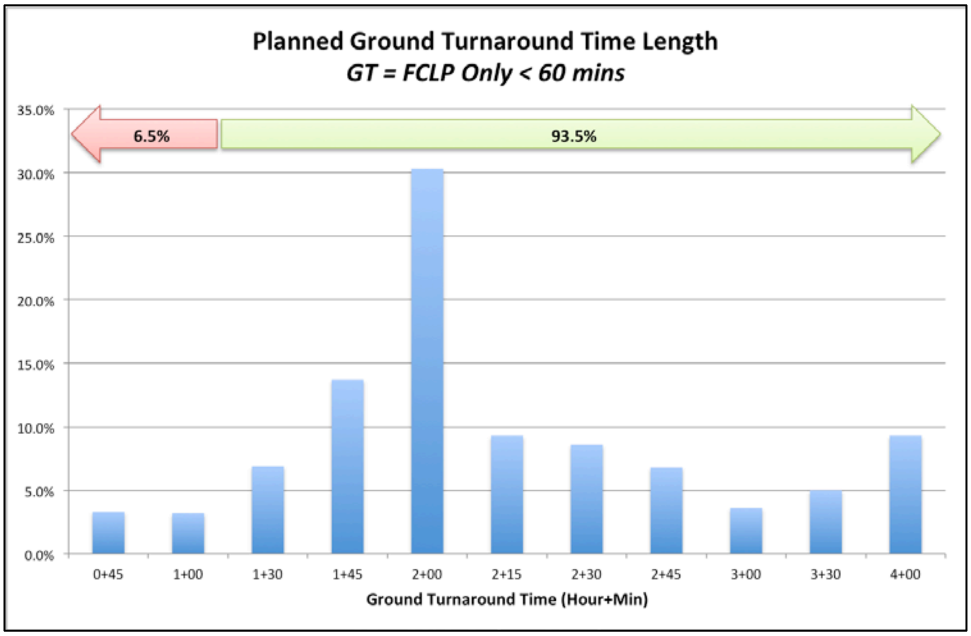


Figure 37. Planned Ground Turnaround Time (FCLP Only < 60 mins)

3. Results

As the percentage of total aircraft planned with ground turnarounds less than or equal to 60 minutes is reduced, the average amount of time an aircraft spends at ground idle is also reduced. Table 13 summarizes the model's output. The only change in this analysis from one policy option to another is the probability that an aircraft will have a ground turnaround of 60 minutes or less. Despite flight schedule planning in the status quo scenario approaching 37 percent, the model's output after 250 replications suggests hot skid usage fell short at 29 percent from primarily flight aborts for insufficient turnaround time. Moreover, hot skid execution usage rates were less than planned at each policy level tested. The remaining scenarios yielded 15.9 percent, 7.6 percent, and 5.2 percent respectively.

Data per Aircraft	Average Minutes at Idle per Aircraft	Std Dev	Sample Size	Margin of Error	Marginal Diff in Minutes
s = 4 / GT FCLP Only	20.82	1.0479	250	0.1305	0.34
s = 4 / GT 10%	21.16	1.2192	244	0.1537	0.67
s = 4 / GT 20%	21.83	1.3033	222	0.1724	1.43
s = 4 / GT StatusQuo	23.27	1.5839	250	0.1973	

Average Sorties per Day	104.29	sorties
Annual Fly Days	250	days
Weighted Average Gallons per Minute	3.42	gallons

Table 13. Ground Turnaround Time Impacts on Time per Aircraft

Figure 38 depicts an average decrease of more than two minutes by restricting aircraft authorized a ground turnaround of 60 minutes or less to 10 percent. Moreover, should leadership find this policy too aggressive, moving from status quo to a 20 percent policy would yield nearly a minute and a half and go a long way toward avoiding non-value added fuel consumption and aircraft operating cost.

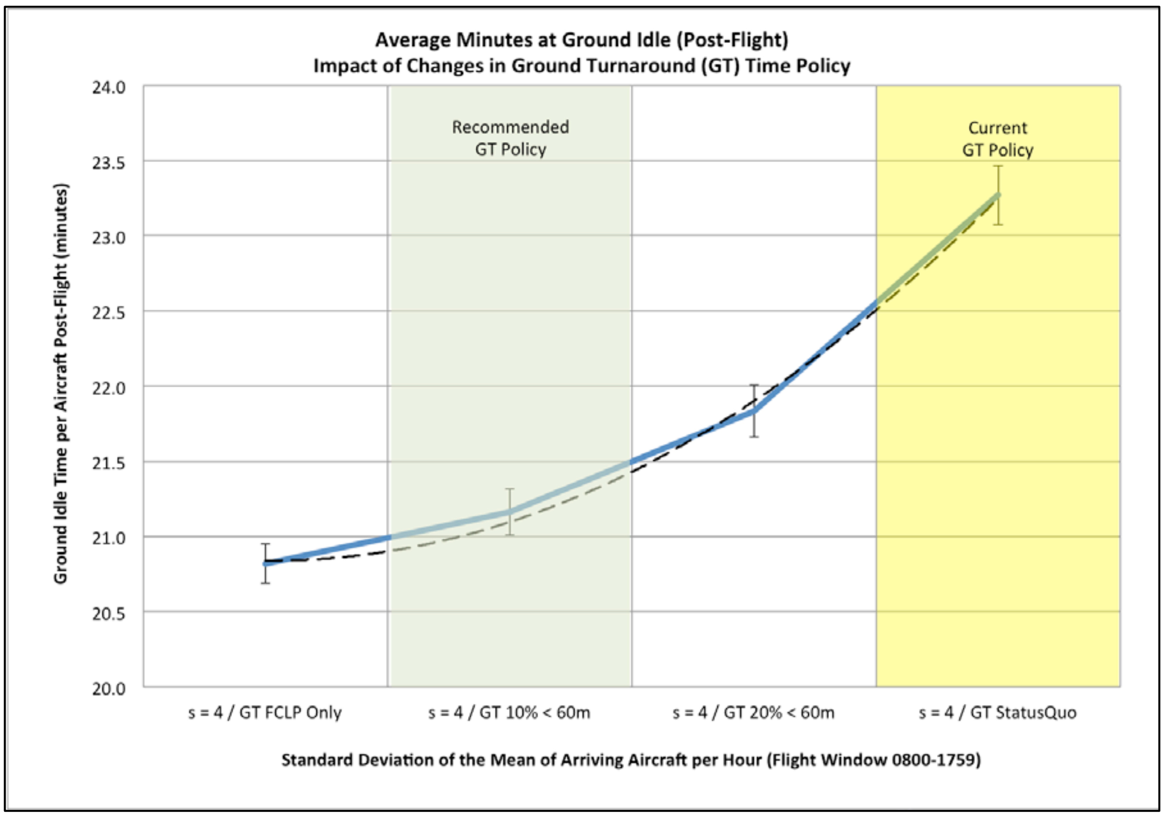


Figure 38. Ground Turnaround Timing Impacts on Time per Aircraft

Table 14, as well as Figures 39 and 40, summarize the incremental change in gallons of fuel consumed per year at the modeled airport. Each scenario, from bottom to top, represents the amount of fuel and cost, on the margin, that can be avoided by adopting a more aggressive ground turnaround policy.

Data per Aircraft	Annual Incremental			
	Gallons	Fuel Cost	Maintenance Cost	Total Cost
s = 4 / GT FCLP Only	30,594	$ 114,729	$ 781,258	$ 895,987
s = 4 / GT 10%	60,044	$ 225,166	$ 1,533,292	$ 1,758,458
s = 4 / GT 20%	127,917	$ 479,688	$ 3,266,494	$ 3,746,182
s = 4 / GT StatusQuo	0	0	0	0

Table 14. Ground Turaround Timing Impacts on Incremental Metrics

Table 15, as well as Figures 39 and 40, summarize the cumulative change in gallons of fuel consumed per year at the modeled airport. Each scenario, from bottom to top, represents the amount of fuel and cost, in cumulative terms, which can be avoided by adopting a more aggressive ground turnaround policy.

Data per Aircraft	Annual Cumulative			
	Gallons	Fuel Cost	Maintenance Cost	Total Cost
s = 4 / GT FCLP Only	218,555	$ 2,004,125	$ 5,581,045	$ 7,585,170
s = 4 / GT 10%	187,961	$ 1,184,543	$ 4,799,786	$ 5,984,329
s = 4 / GT 20%	127,917	$ 479,688	$ 3,266,494	$ 3,746,182
s = 4 / GT StatusQuo	0	0	0	0

Table 15. Ground Turnaround Impacts on Cumulative Metrics

As the percentage of aircraft planned to have ground turnarounds less than or equal to 60 minutes is decreased, there is a substantial fuel and cost avoidance opportunity. Figure 39 depicts the change (decrease) in gallons of fuel consumed per year by adopting one of several ground turnaround timing policies. Using an average of nearly 37 percent of all flights scheduled with a short aircraft turnaround as the base, the gallons of fuel avoided by instituting a 20 percent ground turnaround policy is 127,917 gallons. That is enough fuel to refill 80 F/A-18Es an average of 11,000 pounds (1,600 gallons) each. Our recommendation is to restrict this policy further to 10 percent where an additional 60,044 gallons can be avoided. Of note, further restricting the number of aircraft authorized in planning to have a ground turnaround of less than or equal to 60 minutes below 10 percent is not recommend. There is insufficient evidence to suggest a benefit of reducing this constraint further.

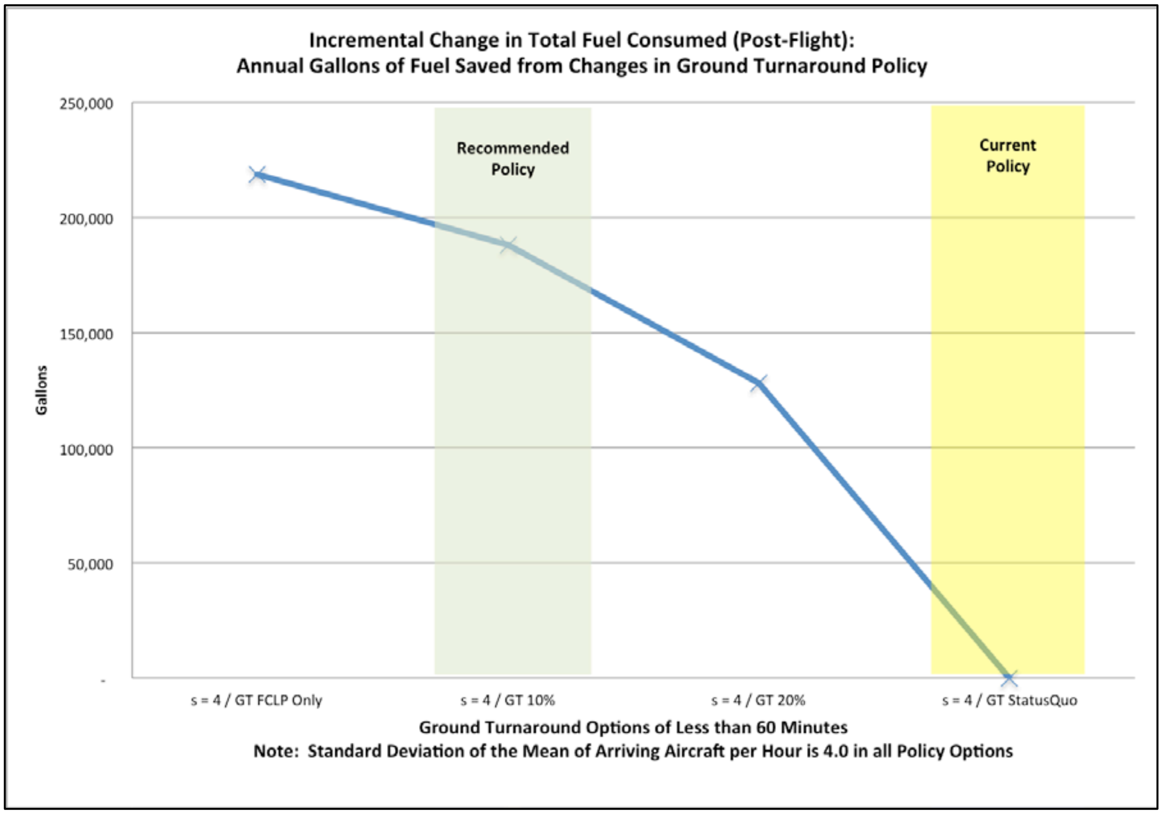


Figure 39. Incremental Change in Total Fuel Consumed (Ground Turn Policy)

Figure 40 depicts the change (decrease) in total aircraft operating cost per year by adopting a more aggressive ground turnaround policy. Using an average of nearly 37 percent of all flights scheduled with a short aircraft turnaround as the base, the aircraft maintenance and fuel costs avoided by adopting a 20 percent ground turnaround policy is \$3,746,182 (FY12) per year. Our recommendation is to further restrict this policy to 10 percent where a total of \$5,984,329 (FY12) in aircraft maintenance and fuel costs can be avoided. Of note, further restricting the number of aircraft authorized in planning to have a ground turnaround of less than or equal to 60 minutes below 10 percent is not recommend. There is insufficient evidence to suggest a benefit of reducing this constraint further.

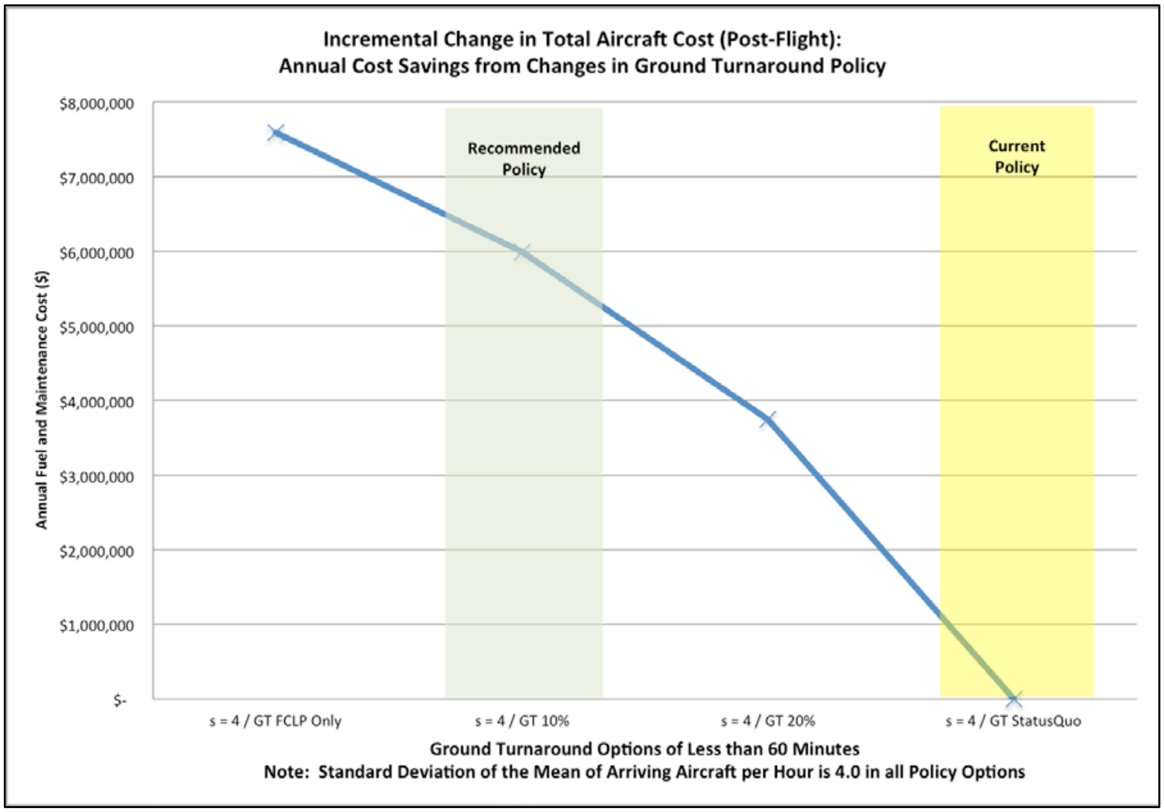


Figure 40. Incremental Change in Total Aircraft Operating Cost (Ground Turn Policy)

D. F/A-18EF TRANSITION IMPACTS

1. Question

What is the marginal impact in both gallons of fuel consumed and aircraft operating cost from continuing operations in similar fashion as today with an all F/A-18 Super Hornet flight line in 2016?

2. Setup

The final experiment in this MBA project is to assess the cost of inaction in adopting a slot management policy, a ground turnaround policy, or both. Over the next two years, NAS Lemoore's flight line will increase by eight F/A-18EF squadrons and sundown all remaining Legacy F/A-18C squadrons (W. Straker, personal communication, May 2, 2013). Now is the time to question all processes, practices, and procedures in use and ensure the criteria that first established each remains valid in an all Super Hornet flight line. By 2016, the entire flight line will behave differently. The current organizational behavior and culture must adapt to this reality and think critically about what this means for routine ground operations.

In this experiment the model was updated to reflect an all F/A-18EF flight line. The new mix of aircraft type is depicted in Table 16. It was assumed for the purposes of this experiment that the two new squadrons joining NAS Lemoore from NAS Oceana will move into Hangar 1 by occupying the spaces vacated by VFA-122's former F/A-18CD aircraft. This was the most conservative assignment possible. Another assumption critical to this experiment was holding the number of fuel trucks constant at 10 (eight 10,000 and two 8,000 gallon trucks).

Aircraft Type in 2016 (F/A-18EF Only)							
Aircraft Type	Probability	Hangar 1	Hangar 2	Hangar 3	Hangar 4	Hangar 5	Totals
FA-18E	50.6%	17.2%	13.1%	12.2%		8.1%	50.6%
FA-18F	49.4%	28.0%	6.7%		14.7%		49.4%
Totals	100.0%	45.2%	19.8%	12.2%	14.7%	8.1%	100.0%

Note: Hangar assignments of the two squadrons relocating to NAS Lemoore is pre-decisional.

Table 16. NAS Lemoore F/A-18EF Only Flight Line by 2016

In this experiment, a side-by-side comparison was made between the current, August 2012, flight line configuration and the future squadron laydown expected by 2016. Each flight line composition was subjected to two arrival variations and two ground turnaround policies. The results are plotted in response curves highlighting gallons of fuel consumed and aircraft operating cost in the next section.

3. Results

Three scenarios of this experiment are presented in Figures 41, 42, and 43. The first two scenarios were similar in that each used a standard deviation of the mean of arriving aircraft per hour of seven. Recall from the slot management experiment that during August, the most common planned schedule variation in aircraft arrival was 7. The difference between the first two scenarios was in the adopted ground turnaround policy, either status quo or the recommended 10 percent ground turn policy. The final side-by-side comparison between the two flight line compositions brings together the recommended standard deviation of the mean of arriving aircraft per hour of 4 with a 10 percent ground turn policy. Each of these three scenarios is presented in both the current, August 2012, flight line configuration and an all F/A-18EF flight line expected by early 2016.

Figure 41 shows the average time each aircraft spends at ground idle during post-flight operations. Contrasting the F/A-18EF flight line with and without accepting any polices in this report results in nearly a two-minute opportunity forgone. The error bars atop each bar indicate the 95 percent confidence interval about the mean and suggest there is no statistical difference between the time spent at ground idle in the current flight line with that of the line forecasted in 2016.

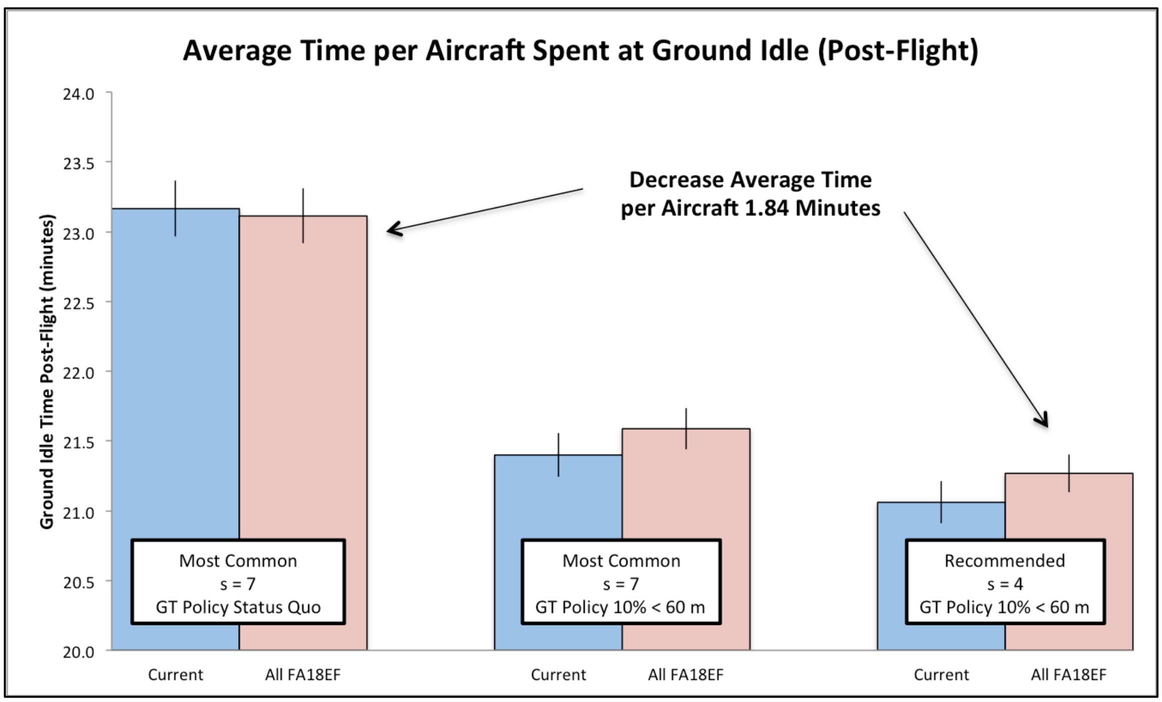


Figure 41. Flight Line Transition Comparison: Average Time per Aircraft

Figure 42 presents an opportunity to avoid 189,245 gallons of fuel in ground operations post-flight. Statistically speaking, this is less than a one percent increase over the current flight line configuration despite having an internal fuel capacity 28 percent larger than the C-variant. Given a 95 percent confidence interval about the mean, there is no statistical difference in gallons of fuel avoided between the current flight line configuration and the all F/A-18EF flight line expected in 2016.

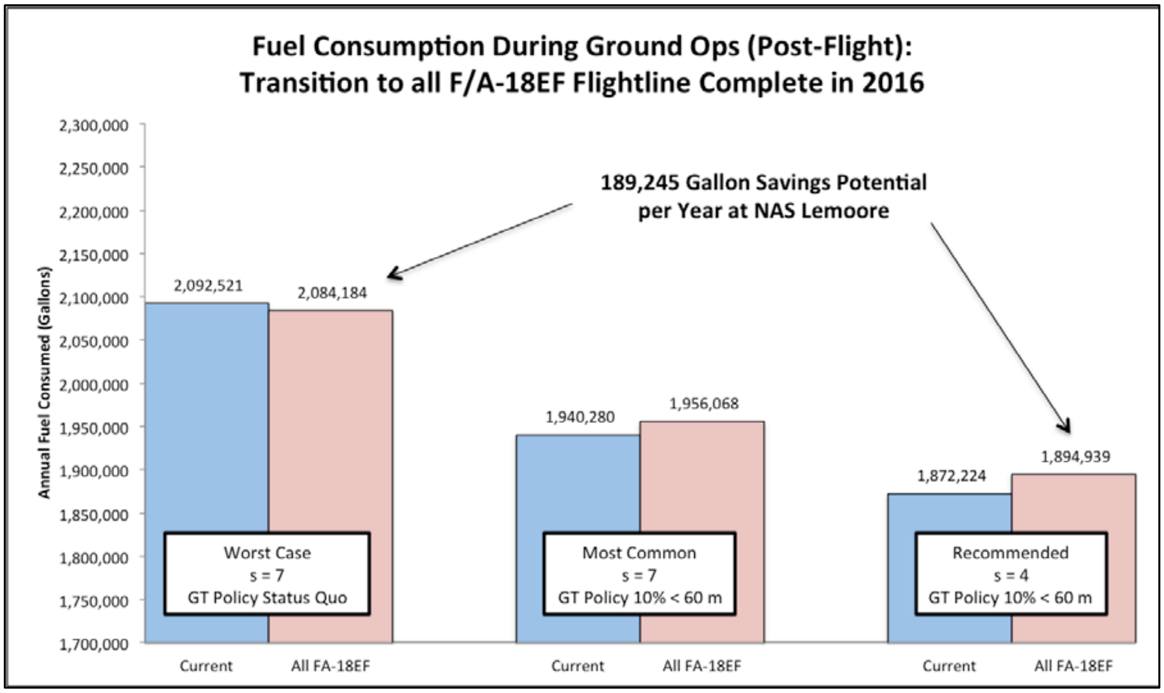


Figure 42. Flight Line Transition Comparison: Fuel Consumption

Figure 43 presents an opportunity to avoid $5,541,273 (FY12) in aircraft maintenance and fuel costs. Relative to the current flight line configuration, this is an 8.0 percent decrease in cost stemming from a significantly cheaper operating cost in the newer F/A-18EF aircraft (Table 17).

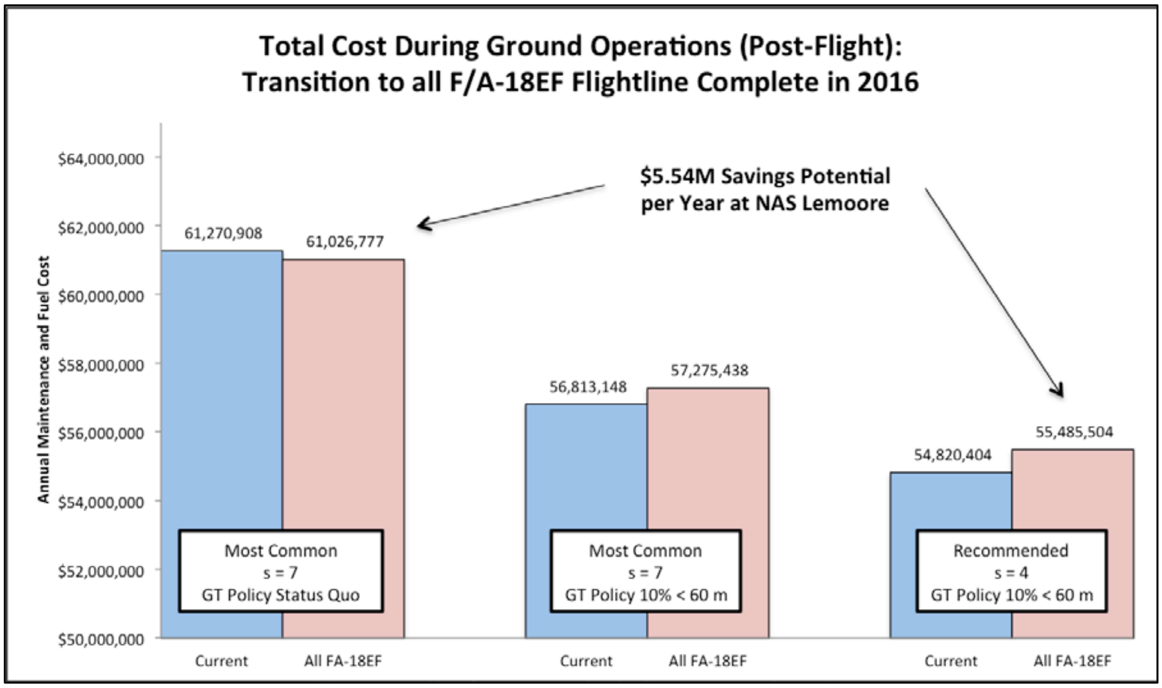


Figure 43. Flight Line Transition Comparison: Aircraft Operating Cost

Daily Mix (Acft Type)		Idle GPM	Fuel Cost per min		Maint Cost per min	
FA-18C mins	30.8%	2.94	$	11.03	$	101.89
FA-18D mins	4.1%	2.94	$	11.03	$	118.83
FA-18E mins	26.5%	3.68	$	13.79	$	76.70
FA-18F mins	38.6%	3.68	$	13.79	$	79.62

Table 17. Aircraft Operating Cost per Minute

V. POLICY RECOMMENDATIONS AND FURTHER STUDY

A. POLICY RECOMMENDATIONS

The objective of this MBA project was to research existing energy conservation commercial and military best practices, evaluate post-ground operations for additional efficiencies, and develop metrics to measure performance at the squadron level. All policies recommended by this study have no impact to operational effectiveness, readiness benchmarks, or safety. Furthermore, because all policy opportunities apply to post-flight ground operations, aircrew should be more prone to adopt these strategies, as they do not reduce flying hours.

Several policy recommendations were identified and analyzed using actual flight data from operations at NAS Lemoore. The results of this study suggest organizational cultural changes are overdue. Moreover, a new approach to cost-wise readiness is necessary to better align the flight line with the energy goals of senior Navy leadership.

Following an exhaustive statistical analysis, we conclude by recommending the following policy changes with respect to post-flight ground operations:

1. Decrease variation in aircraft arrivals during peak periods by establishing a culture of squadron collaboration at the type-wing level through slot management;
2. Promulgate a flight scheduling policy restricting ground turnaround time less than or equal to 60 minutes to 10 percent of all missions flown;
3. Do not increase the number of fuel trucks in service above 10 at NAS Lemoore;
4. Ensure truck and hot skid fuel transfer rates are functioning at peak performance;
5. Minimize tasks performed in hot brake checks to the maximum extent practicable.

Adopting recommendations 1 and 2 outlined above presents a fuel and cost avoidance opportunity extending well beyond NAS Lemoore. Table 18 displays all domestic, land-based, F/A-18 flight hours in 2012. Abstracting from specific post-flight refueling options at each facility and using only flight hours at each air installation as the cost driver, inferences were made. Furthermore, excluded from this table are all flight hours accrued in 2012 from Fleet Readiness Centers (FRC), Naval Test Pilot School (NTPS), Navy Flight Demonstration Squadron (NFDS), as well as VX-23 and VX-31. Assuming both recommendations 1 and 2 are accepted, the total reduction in fuel consumed by F/A-18 aircraft in the DON is 785,775 gallons. Stated another way, $23,008,243 (FY12) in aircraft operating costs could potentially be avoided (Table 18).

F/A-18 Air Installation	2012 Annual Flight Hours Executed							Total Hours	Annual Cost Avoided	Annual Gallons Saved
	EA-18G	FA-18A	FA-18B	FA-18C	FA-18D	FA-18E	FA-18F			
NAS Oceana (KNTU)		2,793.4	886.4	18,829.2	2,027.3	10,287.9	18,316.4	53,140.6	$ 6,904,154	235,790
NAS Lemoore (KNLC)			2.6	11,372.4	1,675.0	9,655.1	26,943.8	49,648.9	$ 6,450,504	220,297
MCAS Miramar (KNKX)		3,231.7	662.2	8,693.3	9,949.1			22,536.3	$ 2,927,970	99,996
MCAS Beaufort (KNBC)		3,936.3		5,794.2	6,309.6			16,040.1	$ 2,083,968	71,171
NAS Whidbey Island (KNUW)	14,218.5							14,218.5	$ 1,847,302	63,089
NAF Atsugi (RJTA)						3,494.9	1,849.3	5,344.2	$ 694,331	23,713
NAS Fallon (KNFL)	528.2	232.2		1,681.0	16.0	479.0	1,681.4	4,617.8	$ 599,956	20,490
NAWS China Lake (KNID)	385.9			455.4	105.0	997.6	1,922.2	3,866.1	$ 502,293	17,154
MCAS Iwakuni (RJOI)				119.7	2,930.5			3,050.2	$ 396,289	13,534
JRB New Orleans (KNBG)		2,786.1						2,786.1	$ 361,977	12,362
JRB Fort Worth (KNFW)		1,843.4						1,843.4	$ 239,499	8,179
	15,132.6	14,823.1	1,551.2	46,945.2	23,012.5	24,914.5	50,713.1	177,092.2	$ 23,008,243	785,775

Table 18. Potential Impacts for NAE

The benefits of slot management and the establishment of a sound aircraft turnaround policy extend beyond refueling efficiencies. Further ground idle time per aircraft is reduced through decreased time spent at the hold short awaiting clearance for takeoff. Then, when in the local training range (i.e., R-2508), there are fewer aircraft from which to deconflict. When aircraft arrivals per hour at an airfield are balanced, aircraft in the respective training ranges are also de-peaked. Backing this notion up one step further suggests the time an aircraft spends at the hold short is also reduced. We assert that any time conserved during preflight ground operations directly enhance inflight training and readiness through increased flight hours.

B. FURTHER STUDY

Our analysis represents only one F/A-18 master jet base and the flight and fuel data from a single month's operations. Applying lessons learned from this report to the other major aviation installations would provide a more comprehensive cost savings estimate across the Naval Aviation enterprise.

The model developed for this project is extremely robust and, although not a deliverable in this report, it could be used to answer many more policy considerations by top-level decision makers. Beyond the scope of our project, but shown in our analysis to offer additional fuel conservation and cost avoidance are the following:

1. Remove all midboard and outboard pylons from F/A-18EF aircraft when operating ashore;
2. Avoid filling external fuel tanks in F/A-18EF aircraft when operating in local airspace ranges ashore to the maximum extent practicable;
3. For routine flight operations, delay engine starts to no earlier than 25 minutes prior to scheduled takeoff;
4. Do not further investigate military power takeoffs in tactical aircraft as a method for fuel savings;
5. Conduct a cost benefit analysis for repairing the Flight-line Electrical Distribution Systems (FLEDS) as a measure to further delay engine start;
6. Research fuel burn and capacity in F-35C Lightning II aircraft and promulgate an appropriate hot refueling policy;

7. Research, develop, and promulgate a dedicated chapter in each aircraft NATOPS Flight Manual addressing energy conservation techniques, practices, and procedures.

C. CONCLUSION

Naval Aviation must adapt to a rapidly changing fiscal and resource environment. Nearly a dozen squadrons are operating at the “tactical hard deck” by flying 40-50 percent of their typical flight hour allocation (T. Branch, personal communication, May 6, 2013). Furthermore, simulator utilization over the past four years has risen significantly suggesting aircrews are augmenting their training and readiness requirements in other ways (Spencer, 2009). From Secretary Mabus to Admiral Greenert and on to Vice Admiral Buss, the direction is clear. Each organization within Naval Aviation is to critically evaluate all practices and processes in search of inefficiencies and waste. Our research shows how this can be done without further reducing flight hours or impacting operational effectiveness.

Naval Aviation’s policies, metrics, and incentives are slowly migrating away from flight hour execution (time) and are now focused on personnel, equipment, and fuel necessary to meet readiness objectives. There are only two metrics for aviation managers to monitor in this study (Figure 44):

1. The ratio between fuel truck and hot skid refueling during peak periods of demand. Maintaining hot skid utilization near 10 percent yields the most significant impact. Establishing periodic communications between the fuel facilities manager and various operational stakeholders enhances awareness and provides the necessary feedback for continued compliance.
2. The actual standard deviation of the mean arrivals per hour (or coefficient of variation) is a good metric for assessing the effectiveness of any slot management initiative. The type wing or air operations staff has this information readily available and can provide periodic feedback to operational stakeholders.

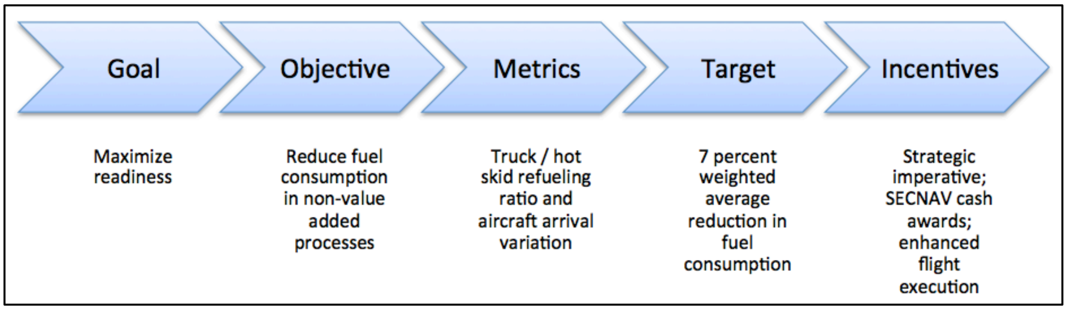


Figure 44. Sustainable Energy Management Value Chain

Figure 44 highlights the value chain introduced in this MBA project. Aligning Naval Aviation's objectives with its goals is an imperative for any lasting solution to its energy challenges. The metrics are explicit and provide a necessary control activity for management to monitor over time. As was noted in the introduction, the i-ENCON program provides cash awards to those ships having the greatest fuel burn reductions from a known baseline without sacrificing days at sea. Naval Aviation would likely see this same cash award program as motivational (Salem et al., 2009). As Air-ENCON matures, increased emphasis on the efficient use of assets can manifest in the Commanding Officer's professional evaluation. Lastly, beyond cash awards and benchmarking among peer squadrons is the opportunity to enhance flight execution through safer ranges as well as more efficient scheduling and stakeholder awareness across the flight line.

APPENDIX A. MODEL SPECIFICATION

A. AIRFIELD

1. Runway

Table 19 establishes the probability of landing on Runway 32L or 32R. Since landings on Runway 14L and 14R occur less than five percent of the time, those values are aggregated in Runway 32L and 32R respectively (T. Atkins, personal communication, January 15, 2013).

Runway Arrival Patterns at NAS Lemoore (August 2012)				
	IFR Arrival	VFR Arrival	Totals	%
32L	1263	781	2044	82%
32R	277	175	452	18%

Note: Only aircraft full stops are included.

Table 19. Runway Arrival Patterns at NAS Lemoore (August 2012)

2. Taxiways

Figure 45 is an annotated NAS Lemoore airfield diagram. Upon landing, all aircraft exit the runway from the same point in an effort to ensure consistence across all experiments. If landing on Runway 32L and proceeding to either Hangar 1, 3, 4, or 5, the aircraft will exit at Taxiway Bravo. For those aircraft landing on Runway 32L and proceeding to Hangar 2, the exiting intersection is Taxiway Alpha. All aircraft landing on Runway 32R clear the runway at Taxiway Foxtrot and taxi southeast toward their respective hangar (DoD, 2012).

Taxi speeds for aircraft and transit speeds for fuel trucks are 10 and 5 miles per hour respectively.

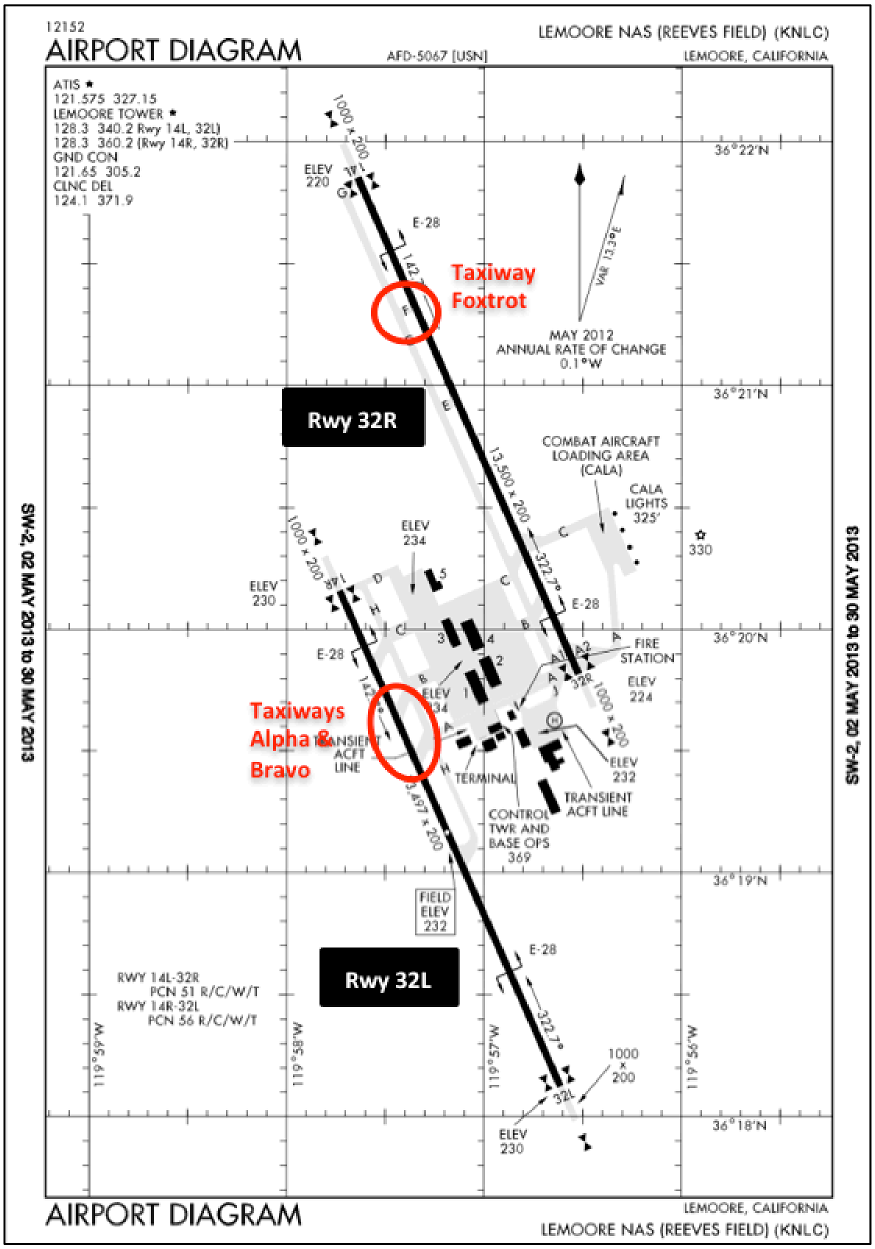


Figure 45. NAS Lemoore Airfield Diagram (After DoD, 2012)

B. AIRCRAFT

1. Engine Burn Rate

Table 20 depicts the engine burn rate assumptions used in the model (CNO, 2011a, 2012a).

Aircraft	Engine	Idle Fuel Flow per Engine
FA-18C	F404-GE-400 /402	600 pph
FA-18D	F404-GE-400 /402	600 pph
FA-18E	F414-GE-400	750 pph
FA-18F	F414-GE-400	750 pph

Table 20. F/A-18 Engine Burn Rate

F/A-18CD 2.941 gallons per minute

Calculation: [[(600 pph)(2 engines)] / (6.8 ppg JP-5) / 60] = 2.941 gpm

F/A-18EF 3.676 gallons per minute

Calculation: [[(750 pph)(2 engines)] / (6.8 ppg JP-5) / 60] = 3.676 gpm

2. Fuel Flow

All aircraft are refueled at a weighted average rate of 185 gallons per minute (Table 21) (CNO, 2011a, 2012a). The F/A-18D makes up less than five percent of all sorties flown and therefore has been omitted from the weighted average calculation.

Fuel Flow Calculations							
	Fuel Capacity (Gallons JP-5)		NATOPS Min	Useable	External	Max FF to Ext	Max FF to Int
Aircraft Type	External Tanks	Internal Tanks	Gallons	Fuel	Fuel Ratio	Tanks (gpm)	Tanks (gpm)
FA-18C	330	1,590	294	1,296	17%	120	200
FA-18E	473	2,162	368	1,794	18%	120	200
FA-18F	473	2,024	368	1,656	19%	120	200

Table 21. Fuel Flow Calculations

Average External Fuel Capacity: 18%

Average Internal Fuel Capacity: 82%

Weighted Average Fuel Flow Transfer Rate: 185.58 gpm

Calculation: (18% ext)(120 gpm) + (82% int)(200 gpm)

3. Average Fly Days per Year

This model assumes the average number of fly days per year is 250. This number reflects allowances for 104 weekend days and 10 federal holidays.

4. Flight Composition

When the model creates a new aircraft it creates them in flights of one, two, three, or four aircraft per flight events to simulate how the real world operates. Analysis was performed of more than 2,600 flight events to determine the probability that a flight event would consist of a single ship, 2-, 3-, or 4-ship (T. Atkins, personal communications, January 15, 2015).

Assuming the number of aircraft arriving at the airport during a given hour is less than the maximum authorized per the time varying arrival table, a random discrete number of aircraft is created per the distribution outlined in Figure 46 and Table 22.

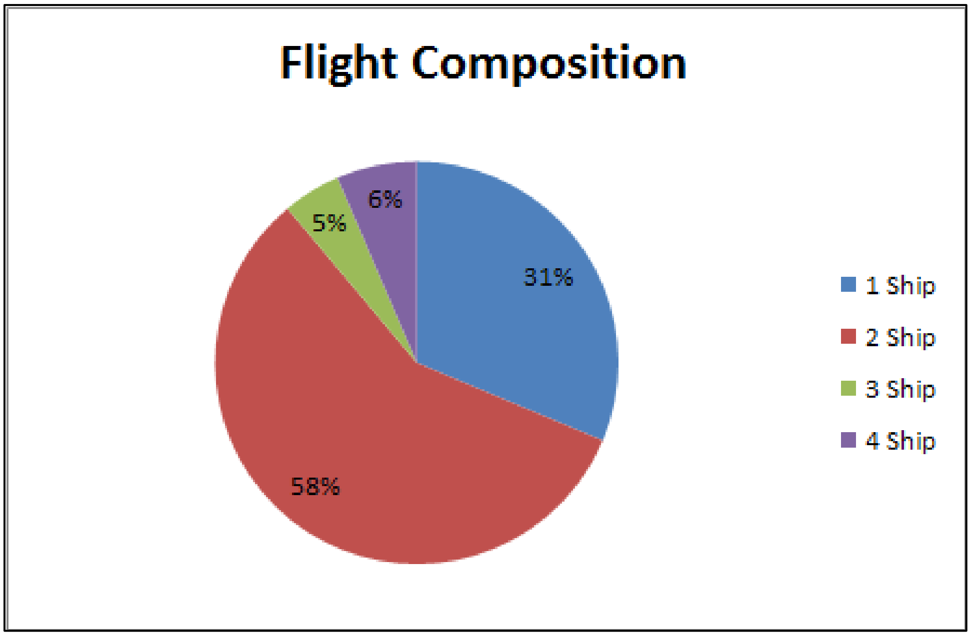


Figure 46. Flight Composition

Flight Composition (Batch Size)					
	1 Ship	2 Ship	3 Ship	4 Ship	Totals
Overall	31.3%	57.6%	4.7%	6.4%	100.0%
F/A-18CD	34.7%	51.5%	6.9%	6.9%	100.0%
F/A-18E	20.4%	68.4%	3.3%	7.9%	100.0%
F/A-18F	36.6%	57.2%	2.1%	4.1%	100.0%
Average	30.6%	59.1%	4.1%	6.3%	100.0%
Average CD	34.7%	51.5%	6.9%	6.9%	100.0%
Average EF	28.5%	62.8%	2.7%	6.0%	100.0%

Table 22. Flight Composition Table

5. Flight Time

Two flight time distributions were required by the model in order to simulate the actual flight time profile. Flight time is the amount of time, in minutes, from takeoff to landing. Using NAS Lemoore's daily air plan reports for the entire month of August 2012, a frequency of each planned flight time was made (T. Atkins, personal communication, January 15, 2012). The information was further stratified by aircraft type in observance of the longer equivalent sortie length in F/A-18EF aircraft. Table 23 summarizes the results.

Flight Time								
	0+45	1+00	1+15	1+30	1+45	2+00	2+30	Totals
Overall	8.2%	7.9%	16.5%	43.9%	16.6%	4.1%	2.8%	100.0%
F/A-18CD	11.0%	3.3%	20.3%	54.9%	7.5%	1.2%	1.9%	100.0%
F/A-18E	3.7%	11.1%	14.1%	33.2%	27.2%	5.7%	5.0%	100.0%
F/A-18F	8.1%	12.9%	12.1%	35.5%	21.8%	7.7%	2.0%	100.0%
Average	7.6%	9.1%	15.5%	41.2%	18.8%	4.9%	3.0%	100.0%
Average CD	11.0%	3.3%	20.3%	54.9%	7.5%	1.2%	1.9%	100.0%
Average EF	5.9%	12.0%	13.1%	34.4%	24.5%	6.7%	3.5%	100.0%

Table 23. Flight Time Table

Figure 47 graphically displays the analysis of flight time and compares the F/A-18CD with that of EF. The F/A-18CD flies the vast majority of its missions in under an hour and a half while the EF comfortably flies in excess of one hour and 45 minutes. This difference affects the model as resources per squadron are restricted to where they are in the readiness cycle.

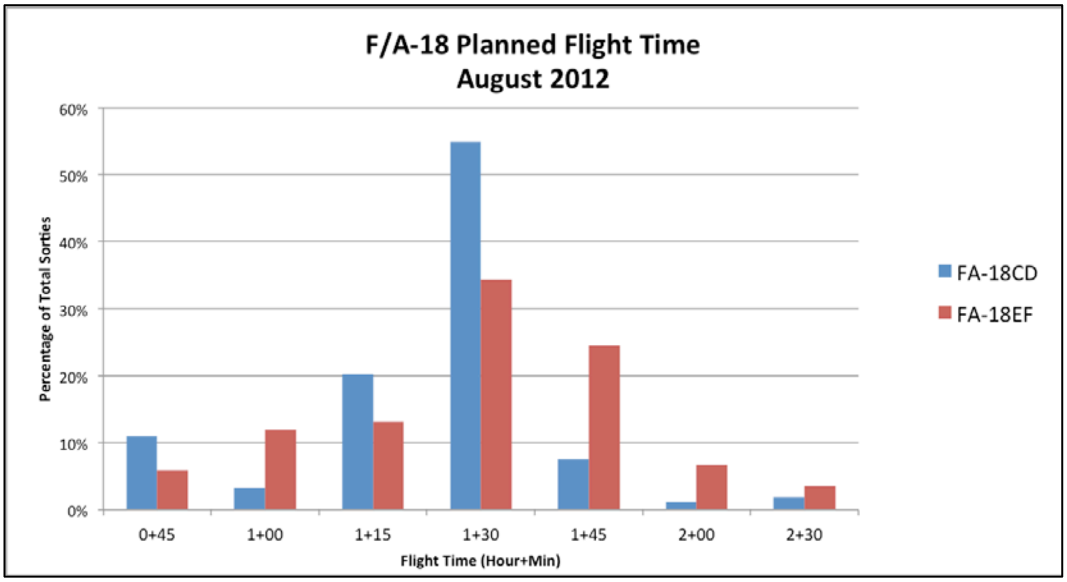


Figure 47. F/A-18 Planned Flight Time

6. Maximum Number of Waves

A single airplane often flies more than once per day. Table 24 depicts the cumulative probability distributions used in the model to mimic an aircraft's likelihood of flying one, two, three, or four waves. Five or more waves occurred less than percent one of the time during August 2012 and, therefore, are omitted (T. Atkins, personal communication, January 15, 2012). Referencing Table 24, the probability that an aircraft will fly two waves is 66 percent. Ensuring steady state conditions, this table was generated using only flights from mid-week sorties.

Maximum Wave Cumulative Distributions					
			1st Wave Launch Window		
Wave	Cumulative	All Day	0800-1759	0800-1459	0800-1159
1	25%	100%	38%	27%	25%
2	66%		100%	71%	66%
3	92%			100%	92%
4	100%				100%

Table 24. Maximum Wave Cumulative Distributions

An aircraft must be constrained in the number of waves permitted in a given day. The time of an aircraft's first launch must also be considered. Table 25 shows the additional restrictions placed on the maximum number of waves through one of four "launch windows." When an aircraft launches in one of these "launch windows," it is aware of the time of day and adjusts its maximum wave accordingly. For example, an aircraft launching between 0800 and 1459 can fly one, two, or three waves. Scheduling a fourth wave with a first launch after 1500 is not possible for mission and ground turnaround constraints.

	Clock		1st Wave Launch Window			
CurrentHour	Time Start	Time End	1 Wave	2 Waves	3 Waves	4 Waves
1	8:00	8:59				
2	9:00	9:59				
3	10:00	10:59				
4	11:00	11:59		Permitted		
5	12:00	12:59				
6	13:00	13:59				
7	14:00	14:59				
8	15:00	15:59				
9	16:00	16:59				
10	17:00	17:59				
11	18:00	18:59				
12	19:00	19:59			Restricted	
13	20:00	20:59				
14	21:00	21:59				
15	22:00	22:59				
16	23:00	23:59				

Table 25. Maximum Wave Launch Windows

7. Aircraft Mix

This model was constructed in a way to enable rapid modification to aircraft type. Specifically, we transitioned the flight line from the current aircraft laydown depicted in Table 26 to what the flight line will look like in the year 2016 (Table 28). Tables 26 and 27 were created to transform real world data to a format suitable for simulation. These tables provide two different views of the same dataset. The first shows the laydown of aircraft per hangar based on aircraft type. For example, of the total volume of aircraft at NAS Lemoore, 7.1 percent of them are F/A-18E's residing in Hangar 5 (NAVAIR, 2012b). Table 27 takes a slightly different view by stratifying according to hangar assignment. For example, of the total F/A-18E population at NAS Lemoore, 26.8 percent of them reside in Hangar 5 (NAVAIR, 2012b).

Aircraft Type (Stratified by Type)							
Aircraft Type	Probability	Hangar 1	Hangar 2	Hangar 3	Hangar 4	Hangar 5	Totals
FA-18C	30.8%	3.4%	17.5%	9.0%		0.9%	30.8%
FA-18D	4.1%	4.1%					4.1%
FA-18E	26.5%	13.8%	2.3%	3.2%		7.1%	26.5%
FA-18F	38.6%	23.9%			14.7%		38.6%
Totals	100%	45.2%	19.9%	12.2%	14.7%	8.0%	100%

Table 26. Aircraft Type (Stratified by Type)

Aircraft Type (Stratified by Hangar)							
Aircraft Type	Probability	Hangar 1	Hangar 2	Hangar 3	Hangar 4	Hangar 5	Totals
FA-18C	30.8%	10.9%	56.9%	29.2%		2.9%	100%
FA-18D	4.1%	100%					100%
FA-18E	26.5%	52.2%	8.8%	12.2%		26.8%	100%
FA-18F	38.6%	61.9%			38.1%		100%
Totals	100.0%						

Table 27. Aircraft Type (Stratified by Hangar)

Looking ahead to 2016 and in support of this project's third research question, the precise laydown of an all F/A-18EF flight line is necessary in ensuring accurate results. Of note, there are currently two squadrons identified to move from NAS Oceana, VA to NAS Lemoore, CA prior to 2016. Their exact hangar assignment was unknown at the time of this writing so the most conservative assignment was made so as to not skew the results. Both of these squadrons were placed in Hangar 1 occupying spaces vacated by former VFA-125 assets (W. Straker, personal communication, May 2, 2013).

Aircraft Type in 2016 (F/A-18EF Only)							
Aircraft Type	Probability	Hangar 1	Hangar 2	Hangar 3	Hangar 4	Hangar 5	Totals
FA-18E	50.6%	17.2%	13.1%	12.2%		8.1%	50.6%
FA-18F	49.4%	28.0%	6.7%		14.7%		49.4%
Totals	100.0%	45.2%	19.8%	12.2%	14.7%	8.1%	100.0%

Note: Hangar assignments of the two squadrons relocating to NAS Lemoore is pre-decisional.

Table 28. Aircraft Type and Hangar Assignment (F/A-18EF Only)

8. Squadron Execution

Two tables were developed for reference during the model run. The first is the a squadron table representing each squadron, aircraft type, probability of flight, hangar and line location, as well as the maximum allowable Ready For Training (RFT) aircraft (Tables 29 and 30) (NAVAIR, 2012b).

Squadron Table (Current, 2012)					
Squadron	Aircraft Type	Squadron Probability	Hangar Select Node	Line Select Node	Max Aircraft
VFA1_C1	1	3.4%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line1	10
VFA1_D2	2	4.1%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line2	4
VFA1_E3	3	13.8%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line3	11
VFA1_F4	4	12.0%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line4	11
VFA1_F5	4	11.9%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line5	12
VFA2_C1	1	5.4%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line1	5
VFA3_C2	1	0.0%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line2	0
VFA4_C3	1	5.4%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line3	5
VFA5_E4	3	2.3%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line4	7
VFA6_C5	1	6.7%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line5	5
VFA7_C1	1	3.6%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line1	5
VFA8_E2	3	3.2%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line2	7
VFA9_C3	1	5.4%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line3	5
VFA10_F2	4	3.4%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line2	8
VFA11_F3	4	5.7%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line3	8
VFA12_F4	4	4.0%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line4	8
VFA13_F5	4	1.6%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line5	8
VFA14_C1	1	0.9%	TransferNode_Hangar5	TransferNode_Hangar5_Line1	5
VFA15_E2	3	0.9%	TransferNode_Hangar5	TransferNode_Hangar5_Line2	7
VFA16_E3	3	6.3%	TransferNode_Hangar5	TransferNode_Hangar5_Line3	6

Table 29. Current Squadron Table and Aircraft Ready for Tasking

The current squadron laydown (Table 29) reflects the NAS Lemoore flight line as of August 2012 (NAVAIR, 2012b). At that time, VFA-122, Fleet Readiness Squadron

(FRS), was still training in the F/A-18CD as well as transitioning one squadron from the C- to E-variant. Table 29 provides the model a wealth of information necessary in creating, routing, and constraining aircraft in the model. The following is an example using row one's data:

Squadron	VFA-1, flying F/A-18C, and parking at Hangar 1, Line 1
Aircraft Type	"1" = F/A-18C "2" = F/A-18D "3" = F/A-18E "4" = F/A-18F
Squadron Prob	Proportion of the entire flight line population
Hangar Select Node	Identifies the hot brake check location
Line Select Node	Identifies the line number of the hangar for parking
Max Aircraft	Restricts the number of squadron aircraft funded to that defined by the VFA Readiness Standard (CNAF, 2011)

Table 30 was created in support of measuring the marginal cost in both gallons of fuel consumed and additional maintenance required once the NAS Lemoore flight line transitions to an all F/A-18EF Super Hornet laydown. To create this table, all six F/A-18C squadrons were transitioned to F/A-18E or F (W. Straker, personal communication, May 2, 2013). Furthermore, in the vacated F/A-18CD lines in VFA-122 at Hangar 1, the two new squadrons were then populated.

Squadron Table (Projected, 2016)					
Squadron	Aircraft Type	Squadron Probability	Hangar Select Node	Line Select Node	Max Aircraft
VFA17_E1	3	3.4%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line1	6
VFA18_F2	4	4.1%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line2	8
VFA1_E3	3	13.8%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line3	11
VFA1_F4	4	12.0%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line4	11
VFA1_F5	4	11.9%	Input@Server_HotBrake_Hangar1	TransferNode_Hangar1_Line5	12
VFA2_E1	3	5.4%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line1	5
VFA3_E2	3	0.0%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line2	0
VFA4_E3	3	5.4%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line3	5
VFA5_E4	3	2.3%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line4	7
VFA6_F5	4	6.7%	Input@Server_HotBrake_Hangar2	TransferNode_Hangar2_Line5	5
VFA7_E1	3	3.6%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line1	5
VFA8_E2	3	3.2%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line2	7
VFA9_E3	3	5.4%	Input@Server_HotBrake_Hangar3	TransferNode_Hangar3_Line3	5
VFA10_F2	4	3.4%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line2	8
VFA11_F3	4	5.7%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line3	8
VFA12_F4	4	4.0%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line4	8
VFA13_F5	4	1.6%	Input@Server_HotBrake_Hangar4	TransferNode_Hangar4_Line5	8
VFA14_E1	3	0.9%	TransferNode_Hangar5	TransferNode_Hangar5_Line1	5
VFA15_E2	3	0.9%	TransferNode_Hangar5	TransferNode_Hangar5_Line2	7
VFA16_E3	3	6.3%	TransferNode_Hangar5	TransferNode_Hangar5_Line3	6

Table 30. F/A-18EF Only Squadron Table and Aircraft Ready for Tasking

9. Aircraft Ready for Tasking Limitations

Table 31 summarizes differences between aircraft assigned and aircraft available for the flight schedule, Ready for Tasking (RFT). The later a squadron is in the 27-month Fleet Readiness Training Plan, the more funding and support they receive. A squadron on deployment is funded at a much higher level than a squadron who has recently returned. The far right column in Table 31 has been rounded up to the next whole aircraft, as the model cannot process a fraction of an aircraft. In row 1, for example, VFA-122 is assigned 20 F/A-18Cs and is funded to operate just 9.2 of them, or 10 for purposes of the model (CNAF, 2011).

Aircraft Ready for Tasking Table						
Hangar	Line	Squadron	Spot Available	Aircraft Assigned	Aircraft In Use	Rounded In Use
1	1	VFA 1 C	8	20	9.2	10
	2	VFA 1 D	8	10	3.3	4
	3	VFA 1 E	10	20	11.0	11
	4	VFA 1 E	10	20	11.0	11
	5	VFA 1 F	10	20	11.9	12
2	1	VFA 2 C	10	10	4.6	5
	2	VFA 3 C	Transitioning to FA-18E			
	3	VFA 4 C	10	10	4.6	5
	4	VFA 5 E	10	12	6.6	7
	5	VFA 6 C	10	10	4.6	5
3	1	VFA 7 C	8	10	4.6	5
	2	VFA 8 E	8	12	6.6	7
	3	VFA 9 C	8	10	4.6	5
	4	EMPTY				
	5	EMPTY				
4	1	EMPTY				
	2	VFA 10 F	10	12	7.1	8
	3	VFA 11 F	10	12	7.1	8
	4	VFA 12 F	10	12	7.1	8
	5	VFA 13 F	10	12	7.1	8
5	1	VFA 14 C	8	10	4.6	5
	2	VFA 15 E	8	12	6.6	7
	3	VFA 16 E	10	10	5.5	6

Table 31. Aircraft Ready for Tasking

C. VARIATION IN AIRCRAFT ARRIVAL RATE

Table 32 is the planned aircraft arrival data compiled from 19 daily air plans at NAS Lemoore during August 2012 (T. Atkins, personal communication, January 15, 2013). Each cell contains the number of aircraft scheduled to arriving during each hour. Then, the standard deviation of the mean of each day was calculated for the period of 0800 to 1759 as well as the time beyond 1800.

Date	8:00	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00	18:00	19:00	20:00	21:00	22:00	23:00	0:00	Std Dev		Squadron Roll-up		FCLP	Sched
																		0800-1759	1800-2359	On Det	Deploy / POM	Yes / No	Sorties
Wednesday, August 1, 12	0	3	9	0	2	16	17	11	5	17	13	6	4	17	9	15	1	6.7	6.0	3	3	Yes	145
Thursday, August 2, 12	0	0	12	14	4	28	13	15	0	0	0	0	0	0	0	0	0	9.4	-	3	3	Yes	86
Friday, August 3, 12	0	0	10	4	27	2	22	0	0	0	0	0	0	0	0	0	0	10.4	-	3	3	Yes	65
Monday, August 6, 12	0	0	4	9	4	10	11	15	1	15	14	10	10	16	15	12	11	5.7	2.4	3	3	Yes	157
Tuesday, August 7, 12	No Data Available																	No Data		3	3	Yes	No Data
Wednesday, August 8, 12	0	0	8	3	4	25	15	4	16	16	13	19	3	13	12	3	2	8.3	6.6	3	3	Yes	156
Thursday, August 9, 12	No Data Available																	No Data		3	3	Yes	No Data
Friday, August 10, 12	0	0	13	9	8	15	10	5	13	6	0	0	0	0	0	0	0	4.7	-	3	3	Yes	79
Monday, August 13, 12	0	0	0	22	4	9	9	7	13	7	4	2	0	1	3	0	0	6.8	1.6		3	No	81
Tuesday, August 14, 12	0	1	16	14	9	5	19	17	10	9	6	2	2	13	11	0	0	5.9	5.3		3	No	134
Wednesday, August 15, 12	0	3	18	18	4	17	13	17	4	16	2	5	4	5	14	0	0	6.6	4.8		3	No	140
Thursday, August 16, 12	0	3	17	18	7	19	17	11	2	13	5	4	0	16	4	0	0	6.5	5.7			No	136
Friday, August 17, 12	0	4	18	17	17	17	12	6	0	4	0	0	0	0	0	0	0	7.1	-			No	95
Monday, August 20, 12	0	4	0	7	9	32	8	17	4	26	16	10	9	21	23	0	0	10.9	9.3			Yes	186
Tuesday, August 21, 12	0	4	26	22	11	24	0	16	17	24	10	0	4	14	26	6	0	9.3	9.2			Yes	204
Wednesday, August 22, 12	0	2	18	20	10	20	19	12	13	12	11	7	8	19	22	0	0	5.9	8.5			Yes	193
Thursday, August 23, 12	1	8	24	20	27	25	17	11	12	8	2	0	9	4	11	0	0	7.5	4.6			Yes	179
Friday, August 24, 12	0	1	5	2	1	0	5	8	1	0	0	0	0	0	0	0	0	2.8	-			Yes	23
Monday, August 27, 12	0	0	1	11	20	26	15	15	26	24	21	16	7	21	18	11	6	9.9	6.3	3		Yes	238
Tuesday, August 28, 12	0	13	12	20	12	21	15	5	21	11	3	2	9	10	14	6	0	5.4	5.0	3		Yes	174
Wednesday, August 29, 12	1	6	12	22	9	19	3	13	21	8	0	4	3	1	11	0	0	6.8	4.0	3		Yes	133
Thursday, August 30, 12	0	3	8	20	21	2	8	15	8	5	7	0	1	4	7	0	0	7.0	3.3	3	3	Yes	109
Friday, August 31, 12	0	0	0	0	3	0	0	4	0	0	0	0	0	0	0	0	0	1.6	-	3	3	Yes	7

Table 32. Planned Aircraft Arrival Matrix at NAS Lemoore (August 2012)

Figure 48 is a histogram of the standard deviation of arriving aircraft per hour during August 2012 (T. Atkins, personal communication, January 15, 2013). The frequency at each variation level provides great insight into scheduling patterns at NAS Lemoore.

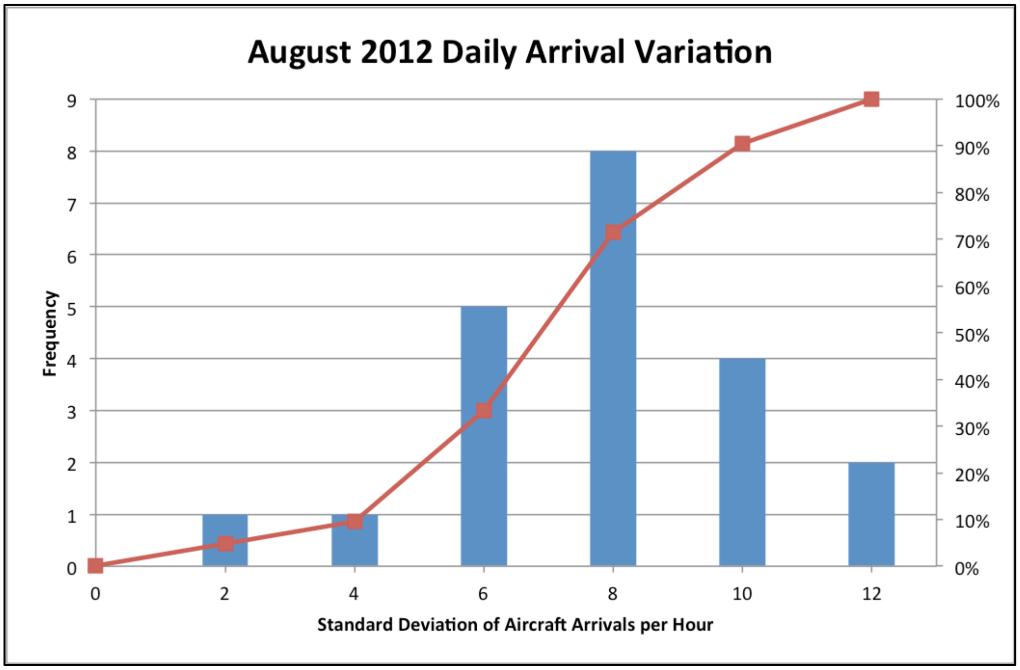
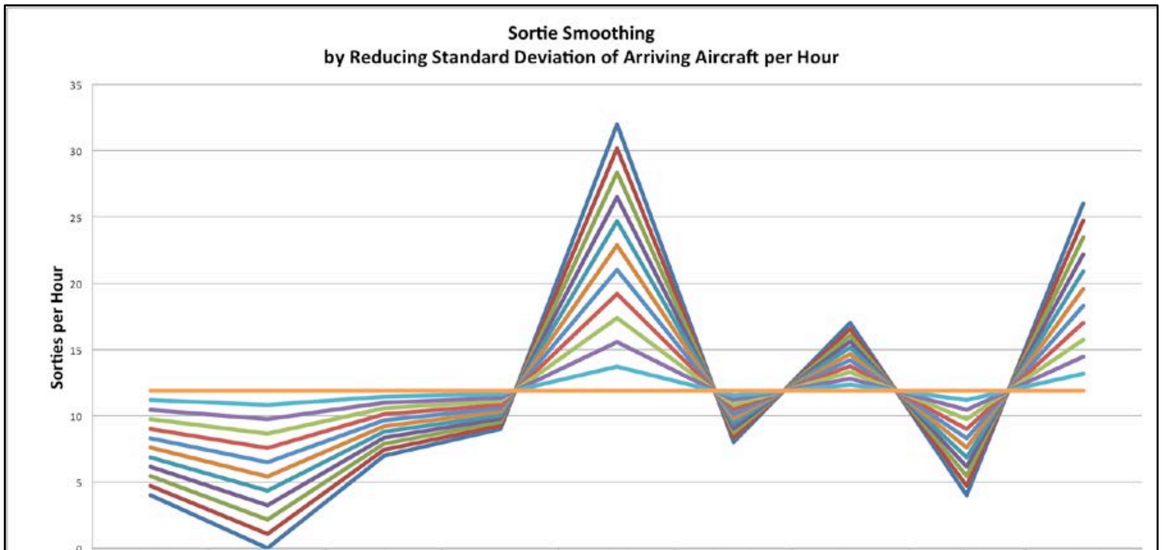


Figure 48. Variation in Aircraft Arrival Rates (August 2012)

The worst-case standard deviation of the mean of arriving aircraft per hour observed was 10.9 on August 20, 2012 (T. Atkins, personal communication, January 15, 2013). Knowing the least variation is at the mean, or average of all arriving aircraft during the period of 0800 to 1759, the extremes were de-peaked in linear fashion from a standard deviation of 11 down to 0 in increments of 1 (Figure 49).



	9:00	10:00	11:00	12:00	13:00	14:00	15:00	16:00	17:00
s = 11	4	0	7	9	32	8	17	4	26
s = 10	5	1	7	9	30	8	17	5	25
s = 9	5	2	8	10	28	9	16	5	23
s = 8	6	3	8	10	27	9	16	6	22
s = 7	7	4	9	10	25	9	15	7	21
s = 6	8	5	9	10	23	10	15	8	20
s = 5	8	6	10	11	21	10	14	8	18
s = 4	9	8	10	11	19	10	14	9	17
s = 3	10	9	11	11	17	11	13	10	16
s = 2	10	10	11	11	16	11	13	10	14
s = 1	11	11	11	12	14	12	12	11	13
s = 0	12	12	12	12	12	12	12	12	12

Figure 49. Sortie Smoothing Technique to De-peak High Demand

The model input table for aircraft arrivals (Table 33), is perhaps the most important data input to the model. Using concepts introduced in Table 32 and Figure 49, this table captures the relationship between time and arrival variation in order to specify the number of aircraft required to arrive in a given hour of time. Each dataset, read vertically along the time axis, can be described using the standard deviation of the mean of arriving aircraft per hour. The standard deviation is an appropriate measure of variation because it is a measure of how spread out a series of numbers is. In this case, how spread out the number of arrivals are per hour throughout the day at an air installation. Moving from left to right across the table, the standard deviation of the mean number of arriving aircraft is reduced incrementally by one. In the far right column is a dataset presenting a standard deviation of 0 indicating a perfectly balanced arrival pattern of aircraft per hour during a 10-hour period. Unique to NAS Lemoore is the field's daily operations do not commence until 0800. For simplification, this model uses the period of 0800 to 0859 as a "warm-up" period to get the simulator functioning at steady state. Therefore, all analysis performed in this project addresses variation in aircraft arrival rates from 0900 to 1759. A screenshot from the Simio implementation is provided as Table 34.

Model Input Table												
Std Dev	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
8:00	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
9:00	4.0	4.7	5.4	6.2	6.9	7.6	8.3	9.0	9.7	10.5	11.2	11.9
10:00	0.0	1.1	2.2	3.2	4.3	5.4	6.5	7.6	8.6	9.7	10.8	11.9
11:00	7.0	7.4	7.9	8.3	8.8	9.2	9.7	10.1	10.6	11.0	11.4	11.9
12:00	9.0	9.3	9.5	9.8	10.1	10.3	10.6	10.8	11.1	11.4	11.6	11.9
13:00	32.0	30.2	28.3	26.5	24.7	22.9	21.0	19.2	17.4	15.5	13.7	11.9
14:00	8.0	8.4	8.7	9.1	9.4	9.8	10.1	10.5	10.8	11.2	11.5	11.9
15:00	17.0	16.5	16.1	15.6	15.1	14.7	14.2	13.7	13.3	12.8	12.4	11.9
16:00	4.0	4.7	5.4	6.2	6.9	7.6	8.3	9.0	9.7	10.5	11.2	11.9
17:00	26.0	24.7	23.4	22.2	20.9	19.6	18.3	17.0	15.7	14.5	13.2	11.9
s	10.9	9.9	8.9	7.9	6.9	5.9	4.9	3.9	3.0	2.0	1.0	0.0
x-bar	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9	11.9
sorties	107.0	107.0	107.0	107.0	107.0	107.0	107.0	107.0	107.0	107.0	107.0	107.0

Table 33. Model Input Table for Aircraft Arrivals

Hour	Max Arrival Per Hour
2/28/2013 8:00:00 AM	0
2/28/2013 9:00:00 AM	9
2/28/2013 10:00:00 AM	8
2/28/2013 11:00:00 AM	10
2/28/2013 12:00:00 PM	11
2/28/2013 1:00:00 PM	19
2/28/2013 2:00:00 PM	10
2/28/2013 3:00:00 PM	14
2/28/2013 4:00:00 PM	9
2/28/2013 5:00:00 PM	17

Table 34. Time Varying Arrival Table (Simio Screenshot of s=4)

Figure 50 depicts the actual landing time distribution about the planned landing time (T. Atkins, personal communication, January 15, 2013; NAVAIR, 2012b). Although the mode of arriving aircraft is at the prescribed landing time, most aircraft land early or very late from their intended, scheduled, landing time. This variation noted on the first arrival of the day is the inherent variation in the arrival of aircraft per hour. All subsequent waves are impacted from the performance of the first arriving wave. In this chart, the average land time is almost one minute late with a standard deviation of 12.8. This means that 68 percent of all landings fall between approximately 12 minutes early to 14 minutes late.

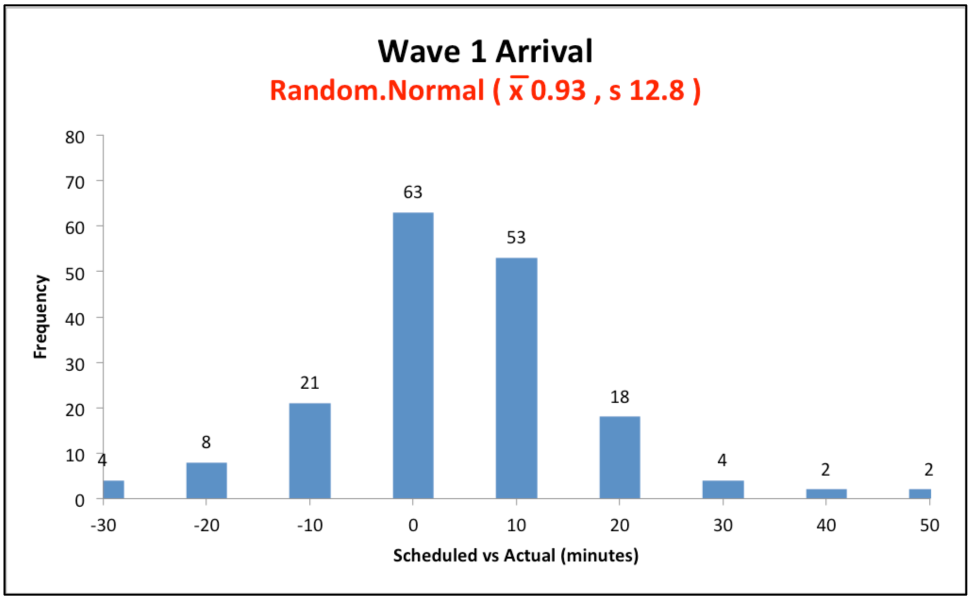


Figure 50. Wave 1 Arrival Variation

In general, when an aircraft takes off on time, it lands on time. Figure 51 depicts the relationship between takeoff and landing. Observe the tendency to land late more than 35 percent of the time despite taking off on time (T. Atkins, personal communication, January 15, 2013; NAVAIR, 2012b).

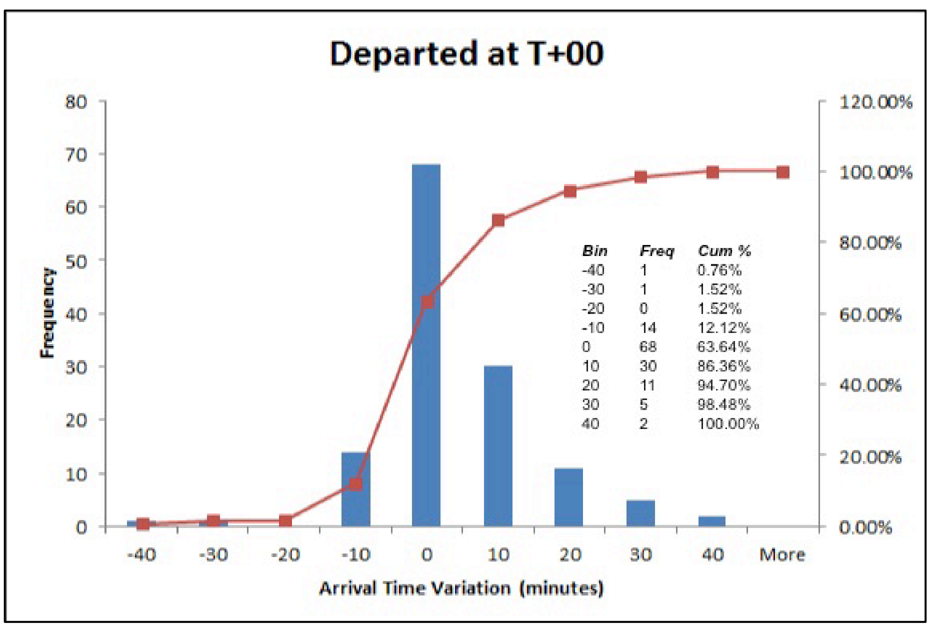


Figure 51. Arrival Variation When Launching on Time

When an aircraft takes off between one and five minutes late, it generally lands on time. However, Figure 52 shows a growing trend to land late more than 45 percent of the time (T. Atkins, personal communication, January 15, 2013; NAVAIR, 2012b).

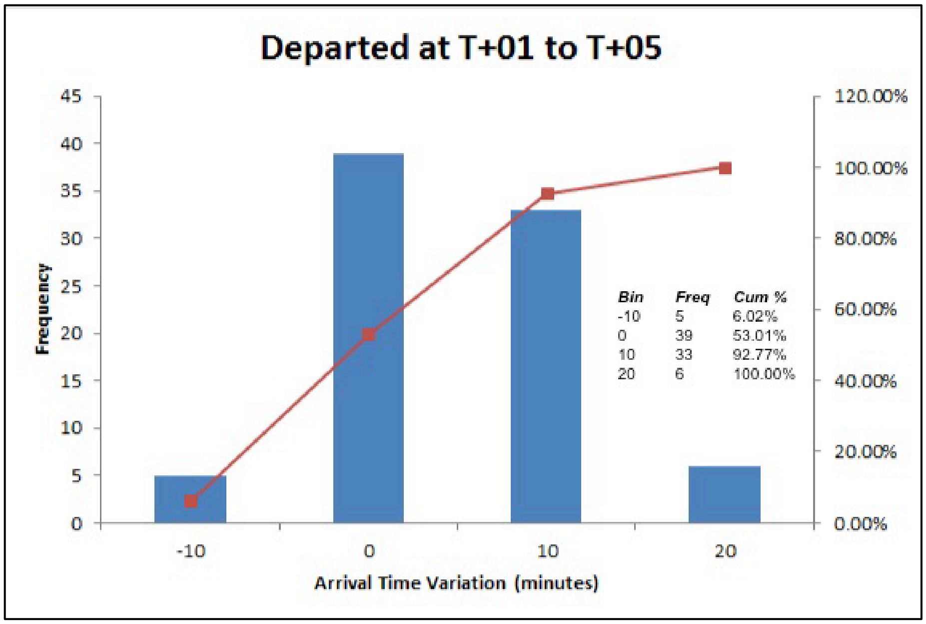


Figure 52. Arrival Variation When Launching 1–5 Minutes Late

Figure 53 highlights aircraft taking off between six and 10 minutes late landing late in nearly all cases (T. Atkins, personal communication, January 15, 2013; NAVAIR, 2012b). This creates planning and resource programming problems for various station stakeholders such as air traffic control, fuel services, and even squadron operations and maintenance since they almost exclusively make decisions based on the planned flight schedule. Any real-time changes to the plan in the form of additions, cancellations, and modifications do not get communicated to all stakeholders in a timely manner, if at all.

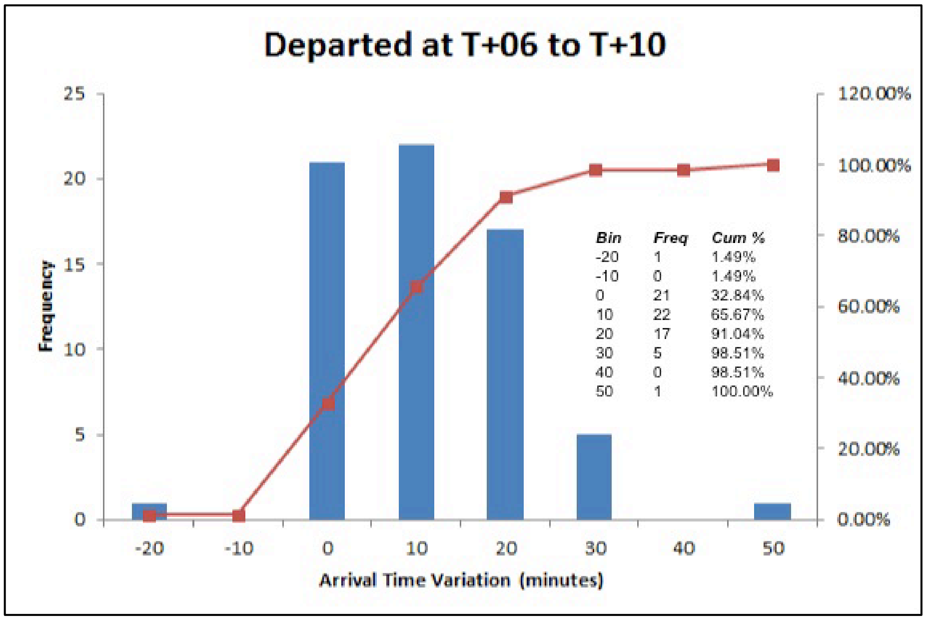


Figure 53. Arrival Variation When Launching 6–10 Minutes Late

In similar fashion to the arrival patterns in launching six to 10 minutes late, Figure 54 depicts a slightly worse condition in launching 11 to 15 minutes late. The key takeaway from this analysis is launching late means landing late (T. Atkins, personal communication, January 15, 2013; NAVAIR, 2012b).

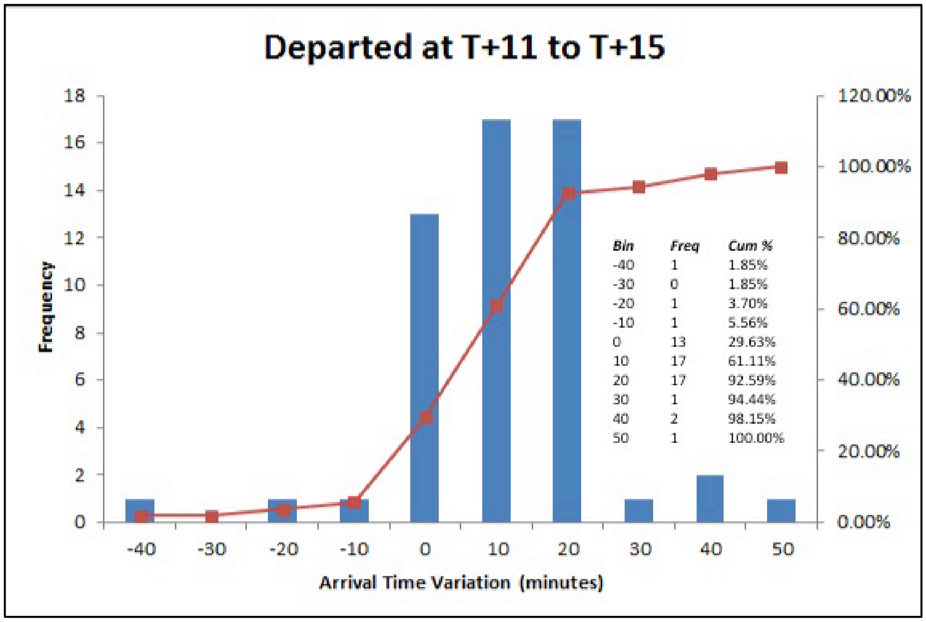


Figure 54. Arrival Variation When Launching 11–15 Minutes Late

The worst arrival patterns were noted when an aircraft launches between 16 and 20 minutes late from their planned departure (T. Atkins, personal communication, January 15, 2013; NAVAIR, 2012b). Almost 80 percent of all missions launching this late will land late (Figure 55).

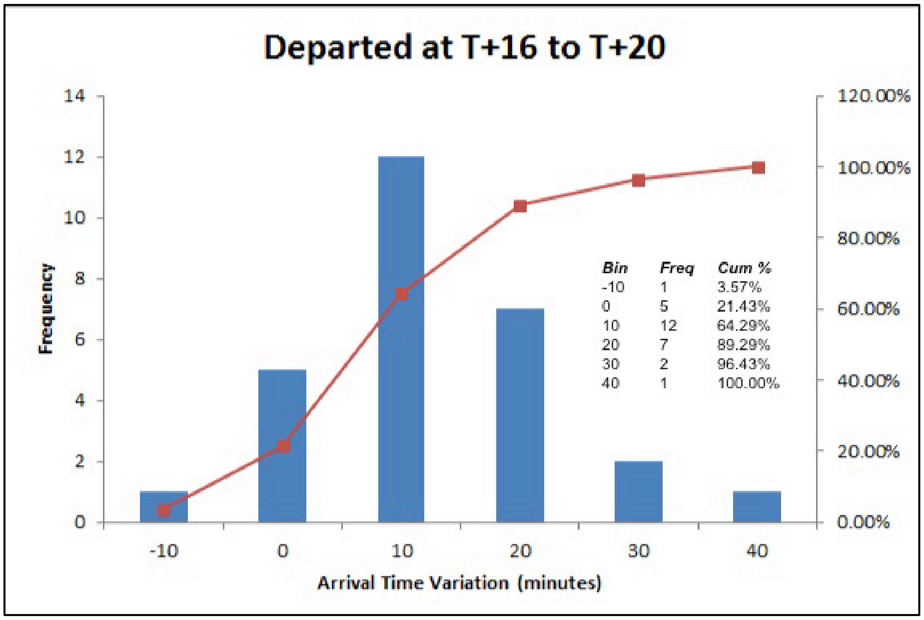


Figure 55. Arrival Variation When Launching 16–20 Minutes Late

D. GROUND TURNAROUND TIMING

The amount of time specified on a squadron's planned flight schedule from the landing of one wave until launching on the next is referred to as ground turnaround. A rule of thumb, and well established business rule on the flight line is any ground turnaround of 60 minutes of less will require hot skid refueling. On the other hand, any planned ground turn of greater than 60 minutes can be satisfied with a fuel truck. All logic implemented in the model is based on this explicit threshold.

Four different ground turnaround policies were explored in this MBA project. The first, status quo, reflects how NAS Lemoore operated during August 2012 between the hours of 0800 to 1759 (Figure 56). The second reflects a modified distribution of the first where only 20 percent of all missions may be planned with a ground turnaround of less than or equal to 60 minutes (Figure 57). This does not restrict the hot skid usage to something less than 20 percent. This constraint is applied in the planning stages only. During execution, a number of real-time events may trigger an aircraft once schedule for a fuel truck to require a hot skid in order to make the launch time of a subsequent wave. The third restricts planned ground turnaround time to 10 percent of all missions scheduled (Figure 58) and the fourth to only those missions absolutely requiring a hot skid to be successful (Figure 59). The only mission determined by this study to require hot skid refueling is that of field carrier landing practice (FCLP) (T. Atkins, personal communication, January 15, 2013). This mission involves numerous flights of short during focusing on a singular task at the local airfield. For efficiency and operational effectiveness, the hot skids are necessary in support of FCLP mission (TMR code 1A3) representing 6.5% of the total training continuum (Table 35).

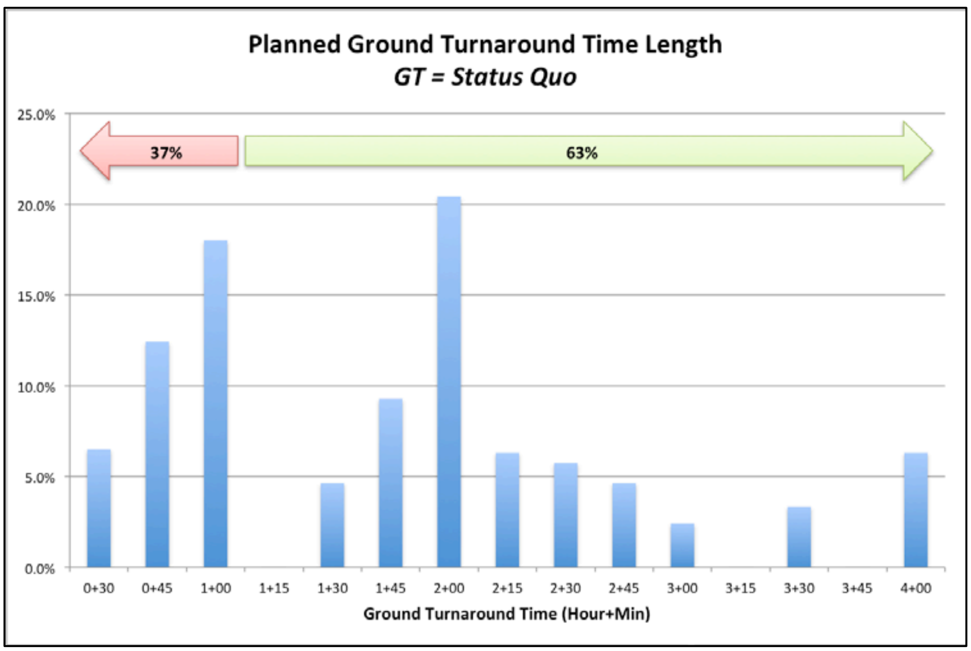


Figure 56. Planned Ground Turnaround Time (Status Quo)

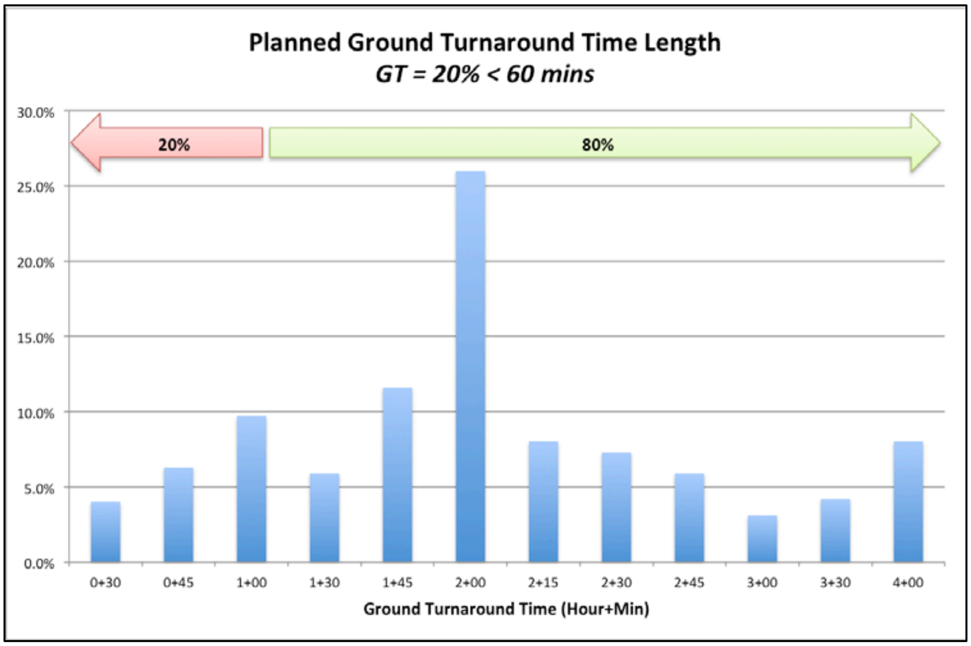


Figure 57. Planned Ground Turnaround Time (20% < 60 mins)

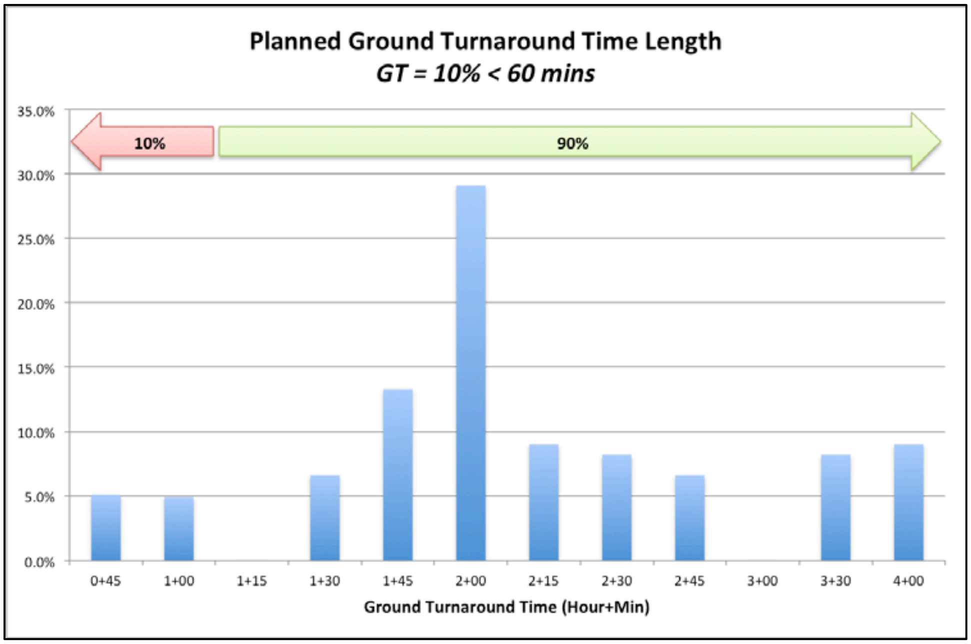


Figure 58. Planned Ground Turnaround Time (10% < 60 mins)

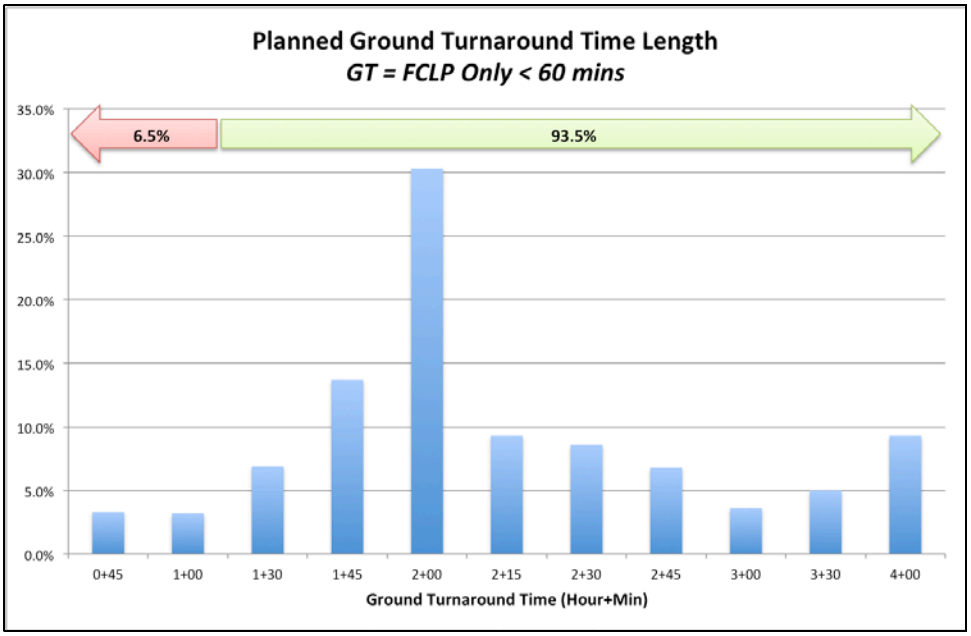


Figure 59. Planned Ground Turnaround Time (FCLP Only < 60 mins)

Flights Requiring Field Carrier Landing Practice (FCLP)

TMR	F/A-18C	TMR	F/A-18E	TMR	F/A-18F
1A0	9	1A0	2	1A0	4
1A1	358	1A1	232	1A1	532
1A2	23	1A2	30	1A2	27
1A3	176	1A3	115	1A3	164
1A4	38	1A4	6	1A4	14
1A5	10	1A5	4	1A5	23
1A6	928	1A6	485	1A6	840
1A7	659	1A7	275	1A7	743
1A8	1	1A9	4	1A9	8
1A9	1	1B6	4	1B1	4
1B1	2	1B7	3	1B6	22
1B6	17	1C1	3	1B7	8
1B7	12	2J1	3	1C1	14
1C1	6	2J2	13	1C5	1
1F1	2	2K0	1	1F1	4
1I3	1	2K2	10	1G1	18
2J1	1	2K4	242	1G6	41
2J2	93	2K7	7	1G7	49
2K0	1	2K8	2	1G9	2
2K1	3	2K9	1	2J1	7
2K2	121	2L0	33	2J2	65
2K3	6	2L1	24	2K0	2
2K4	190	2L7	1	2K1	1
2K6	1	2L9	16	2K2	16
2L0	79	2Q4	8	2K4	204
2L1	6	2Q6	2	2K7	4
2L2	1	3S2	1	2L0	34
2L9	13		**1527**	2L1	16
2M6	2			2L3	1
2Q4	33			2L5	16
	2793			2L9	51
				2Q1	3
				2Q4	23
				2Q6	2
				3S2	1
					2964
6.3%	FCLP	7.5%	FCLP	5.5%	FCLP

Table 35. Flights Engaged in Field Carrier Landing Practice (FCLP)

Figure 60 introduces a special ground turnaround policy used during the slot management experiment. In order to isolate the affects from reducing the standard deviation of the mean of arriving aircraft per hour, hot skid usage during the planning phase was restricted to zero. During the model run, the hot skids were available to those aircraft experiencing a shorter than planned (less than or equal to 60 minutes) ground turnaround due to unforeseen circumstances.

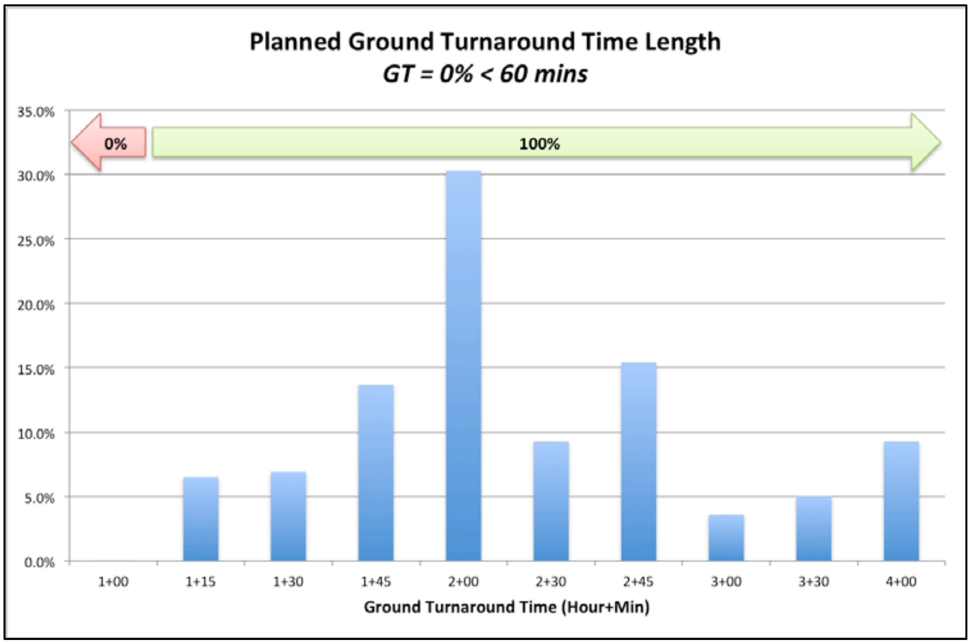


Figure 60. Planned Ground Turnaround Time (0% < 60 mins)

E. TRUCK REFUELING

1. Level of Service

There are ten total trucks assumed in service each fly day without fail. Of the 10 operational trucks, eight were 10,000 gallon and two 8,000 gallon trucks. Interviews with the NAS Lemoore Fuel Facilities Manager, revealed two to three fuel trucks out of service on any given day (G. Blocker, personal communication, January 24, 2013). These trucks are above the ten fuel trucks in service.

Fuel trucks transfer fuel at a rate of 120 gallons per minute (gpm) when filling the external fuel tanks and 200 gpm when filling the internal fuel tanks. For modeling purposes, this equates to a weighted average of 185 gpm. The fuel trucks, on the other hand, refill at a fill stand using a rate of fuel transfer between 450 and 500 gallons per minutes (G. Blocker, personal communication, January 24, 2013). The model uses the median fuel flow rate of 475 in calculating the amount of time necessary to refill a truck after reaching a state below 2,500 gallons remaining.

All fuel trucks in service are assumed to be 100 percent reliable. The only time during model run that a truck is in a failed status is during the refill process at a fill stand (hot skid). In addition, all fuel trucks refill when their internal fuel capacity reaches 2,500 gallons of fuel remaining. Crossing that threshold negatively triggers a process that sidelines the truck to receive fuel from a fill stand.

2. Truck Refuel Demand

Analysis of over 4,300 refueling events at NAS Lemoore during August 2012 led to the development of a fuel demand profile for each aircraft (G. Blocker, personal communication, January 16, 2013). Of all refueling events, fuel trucks successfully completed 2,894 refueling events. Furthermore, transient aircraft (e.g., C-40, F-16, F/A-18s from other airbases), ground support equipment (fire trucks, forklifts, sweepers), and defuels for maintenance were excluded in preparing Table 36.

Fuel Truck Demand Table (Gallons)							
F/A-18C		F/A-18D		F/A-18E		F/A-18F	
Qty	Cumulative Prob	Qty	Cumulative Prob	Qty	Cumulative Prob	Qty	Cumulative Prob
100	5.6%	100	17.4%	100	4.7%	100	5.9%
200	12.4%	200	21.7%	200	7.6%	200	10.9%
300	15.7%	300	23.5%	300	10.7%	300	13.6%
400	19.2%	400	26.1%	400	12.0%	400	15.1%
500	22.5%	500	30.4%	500	13.6%	500	16.8%
600	24.8%	600	31.3%	600	16.6%	600	19.3%
700	26.7%	700	33.9%	700	17.6%	700	20.5%
800	30.8%	800	36.5%	800	18.6%	800	22.1%
900	33.6%	900	39.1%	900	19.7%	900	23.7%
1000	37.4%	1000	40.9%	1000	21.8%	1000	24.8%
1100	40.3%	1100	47.8%	1100	24.2%	1100	27.1%
1200	44.1%	1200	57.4%	1200	26.0%	1200	29.4%
1300	49.4%	1300	66.1%	1300	27.6%	1300	31.1%
1400	56.3%	1400	81.7%	1400	30.7%	1400	35.0%
1500	65.7%	1500	95.7%	1500	36.6%	1500	37.5%
1600	80.2%	1600	100.0%	1600	42.7%	1600	42.1%
1700	90.5%	1700	100.0%	1700	48.4%	1700	47.9%
1800	93.2%	1800	100.0%	1800	56.6%	1800	54.0%
1900	95.6%	1900	100.0%	1900	62.5%	1900	62.3%
2000	99.1%	2000	100.0%	2000	69.8%	2000	72.2%
2100	100.0%	2100	100.0%	2100	76.8%	2100	86.3%
				2200	85.5%	2200	97.3%
				2300	94.0%	2300	99.4%
				2400	98.8%	2400	99.6%
				2500	100.0%	2500	100.0%

Table 36. Fuel Truck Demand Table

Figures 61 through 64 reflect the discrete frequency distributions of the F/A-18C, D, E, and F respectively. There were 864 F/A-18C refueling events, 115 F/A-18D events, 800 F/A-18D events, and 1,115 F/A-18F events (G. Blocker, personal communication, January 16, 2013).

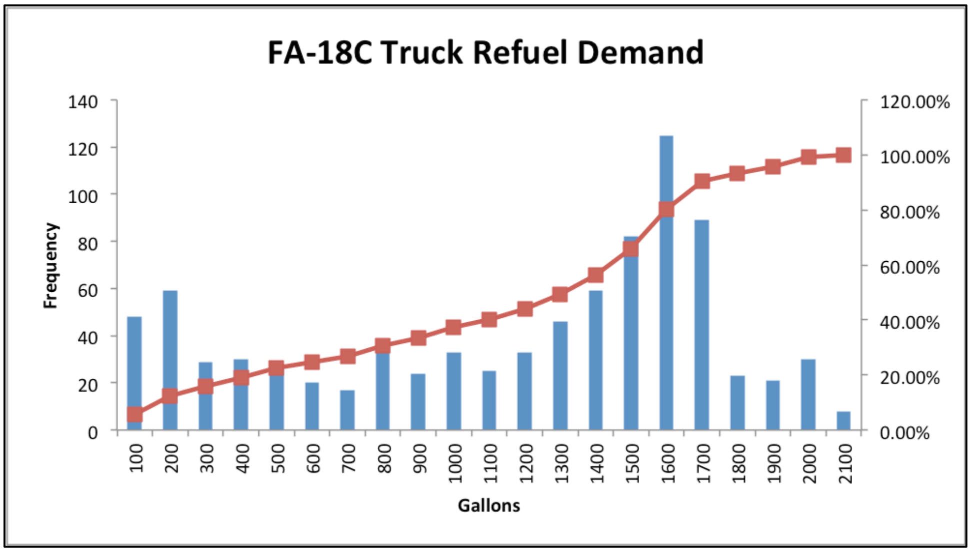


Figure 61. F/A-18C Truck Refuel Demand

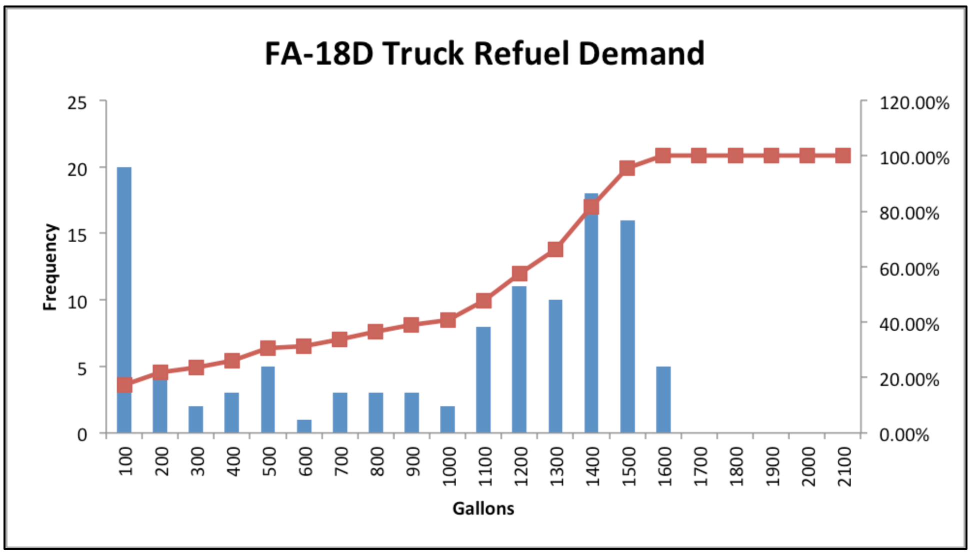


Figure 62. F/A-18D Truck Refuel Demand

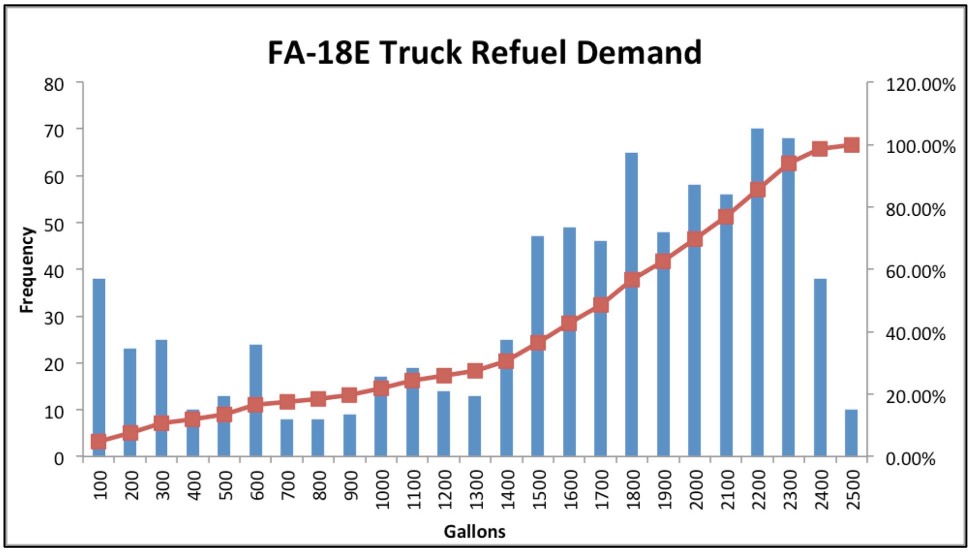


Figure 63. F/A-18E Truck Refuel Demand

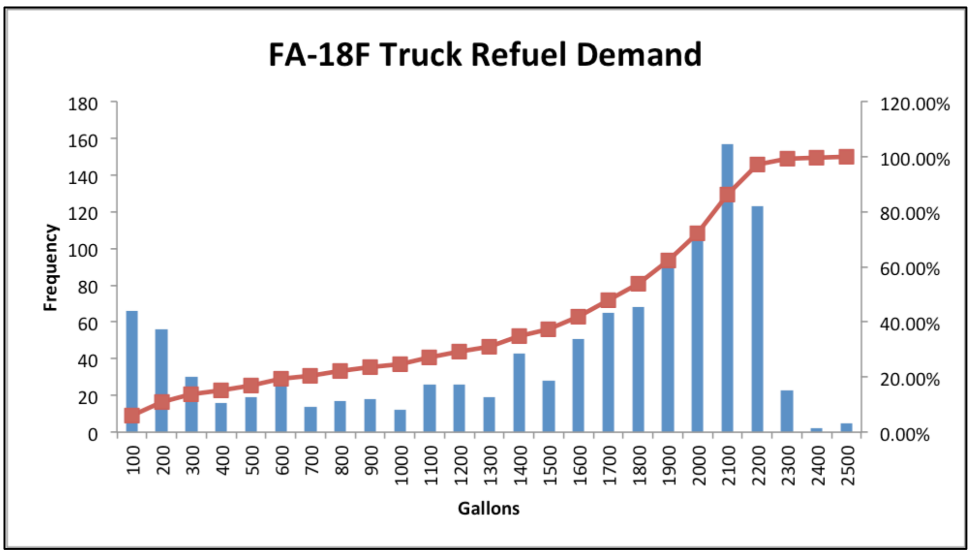


Figure 64. F/A-18F Truck Refuel Demand

3. Fuel Truck Decision Criteria

As an aircraft approaches the hot brake check process after clearing the runway on landing, a decision must be made as to whether there is sufficient fuel truck capacity available. If the aircraft has a ground turnaround time less than or equal to 60 minutes, the aircraft is flagged for hot skid refueling. On the other hand, if the aircraft has a ground turnaround greater than 60 minutes, it now must determine the likelihood that a fuel truck is available to provide servicing no later than 30 minutes prior to the next departure. In the real world, there are many variables affecting a squadron's decision to wait for a fuel truck, or cycle the aircraft through the hot skids based. It's a risk assessment performed when the aircraft recovers. This model uses a very simple algorithm to make a decision to use the hot skids or continue to the line for a fuel truck (Figure 65).

Fuel Truck Decision Criteria

Step 1: Calculate Time Available for Refueling

Aircraft Ground Turnaround Time	120 mins
Time Required for Start/ Taxi/ Takeoff in Next Wave	30 mins
Time Remaining for Refueling	90 mins

Step 2: Calculate Fuel Truck Cycle Time (per Truck)

Average Fuel Available for Transfer	7500 gallons
Average Fuel Demand per Aircraft	1600 gallons
Average Number of Aircraft Serviced per Truck	4.7 aircraft
Average Aircraft Servicing Time	15 mins
Average Number of Aircraft Serviced per Truck	4.7 aircraft
Total Time Required per Truck for Aircraft Servicing	70.3 mins
Average Fuel Truck Refill Time	20 mins
Total Time for Aircraft Servicing and Truck Refill	90.3 mins

Step 3: Calculate the Maximum Number of Aircraft Acceptable in Queue

Time Remaining For Refueling (Step 1)	90 mins
Cycle Time for Fuel Truck (Step 2)	90.3 mins
Fuel Trucks in Service	4 trucks

Formula: (Window / Cycle Time) x Trucks x Acft Svc per Truck
(90 mins / 90.3 mins) x 4 Trucks x 4.7 Acft Svc per Truck

Maximum Aircraft in Queue: 19

Decision
If the number of aircraft waiting for a truck is less than or equal to 19, the aircraft will continue as planned. If, more than 19 are in the queue for the fuel trucks, the aircraft will go through the hot skids and then shutdown in the line where it awaits the next flight event.

Figure 65. Fuel Truck Decision Criteria Algorithm

4. Fuel Truck Fill Stand Demand

Whenever a truck's fuel remaining decreases below 2,500 gallons remaining, it will finish its current refueling event and then proceed direct to a fill stand for refill. Table 37 and Figure 66 summarize 603 fill stand events during August 2012 (G. Blocker, personal communication, January 16, 2013).

Fuel Truck Fill Stand Demand Table (Gallons)	
Qty	Cumulative Prob
500	1.2%
1000	2.5%
1500	3.8%
2000	6.8%
2500	8.3%
3000	10.3%
3500	13.3%
4000	16.7%
4500	21.9%
5000	25.9%
5500	28.9%
6000	34.3%
6500	39.1%
7000	45.8%
7500	51.6%
8000	59.0%
8500	70.5%
9000	81.8%
9500	91.5%
10000	100.0%

Table 37. Fuel Truck Fill Stand Demand Table

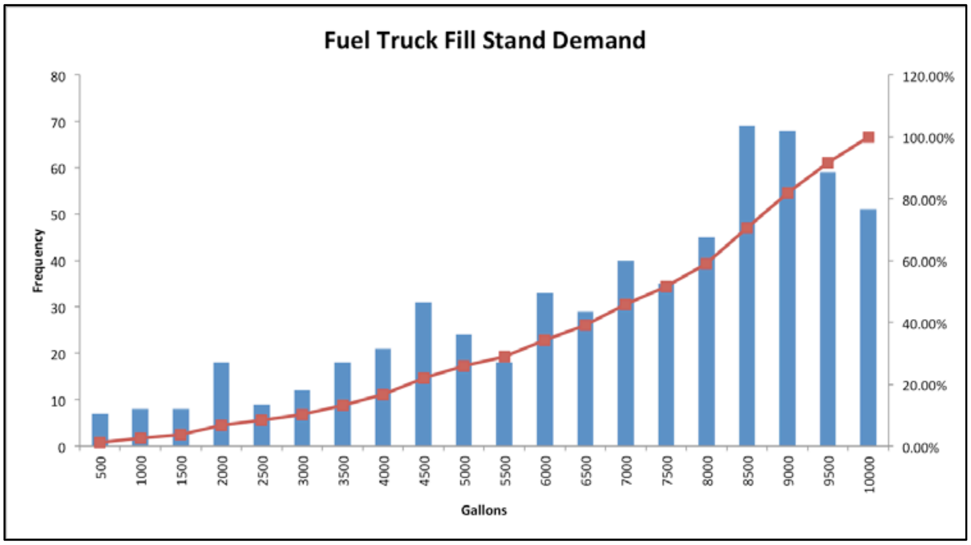


Figure 66. Fuel Truck Fill Stand Demand

F. HOT SKID REFUELING

1. Level of Service

There are 10 hot skids consisting of two lanes each at NAS Lemoore. Each hot skid has an unlimited capacity to provide fuel to both aircraft and fuel trucks when refilling and is assumed 100 percent reliable. The hangar and hot skid pairing is depicted in Table 38.

NAS Lemoore Hangar / Hot Skid Pairing				
Hangar 1	Hangar 2	Hangar 3	Hangar 4	Hangar 5
1 Left	3 Left	5 Left	7 Left	9 Left
1 Right	3 Right	5 Right	7 Right	9 Right
2 Left	4 Left	6 Left	8 Left	10 Left
2 Right	4 Right	6 Right	8 Right	10 Right

Table 38. Hangar/Hot Skid Pairing

The hot skids transfer fuel at a rate of 120 gallons per minute (gpm) when filling the external fuel tanks and 200 gpm when filling the internal fuel tanks. For modeling purposes, this equates to a weighted average of 185 gpm. On the other hand, if a fuel truck requires a refill, the transfer rate used is 475 gpm (G. Blocker, personal communication, January 24, 2013).

2. Hot Skid Refuel Demand

Analysis of over 4,300 refueling events at NAS Lemoore during August 2012 led to the development of a fuel demand profile for each aircraft (G. Blocker, personal communication, January 16, 2013). Of all refueling events, hot skids successfully completed 531 refueling events. Furthermore, transient aircraft (e.g., C-40, F-16, F/A-18s from other bases), ground support equipment (fire trucks, forklifts, sweepers), and defuels for maintenance were excluded in preparing Table 39.

Hot Skid Demand Table (Gallons)							
F/A-18C		F/A-18D		F/A-18E		F/A-18F	
Qty	Cumulative Prob	Qty	Cumulative Prob	Qty	Cumulative Prob	Qty	Cumulative Prob
100	1.1%	100	0.0%	100	0.6%	100	0.8%
200	3.9%	200	0.0%	200	3.0%	200	3.3%
300	5.2%	300	1.9%	300	4.2%	300	4.4%
400	7.0%	400	4.4%	400	5.7%	400	6.0%
500	9.4%	500	7.8%	500	7.8%	500	8.1%
600	14.2%	600	14.7%	600	11.9%	600	12.3%
700	20.5%	700	23.8%	700	17.4%	700	17.9%
800	26.4%	800	32.3%	800	22.5%	800	23.1%
900	32.8%	900	41.4%	900	28.0%	900	28.7%
1000	37.3%	1000	48.0%	1000	32.0%	1000	32.7%
1100	40.6%	1100	52.7%	1100	34.8%	1100	35.6%
1200	43.4%	1200	56.7%	1200	37.3%	1200	38.1%
1300	47.6%	1300	62.7%	1300	40.9%	1300	41.7%
1400	51.1%	1400	67.7%	1400	43.9%	1400	44.8%
1500	59.0%	1500	79.0%	1500	50.8%	1500	51.7%
1600	68.3%	1600	92.5%	1600	58.9%	1600	60.0%
1700	75.8%	1700	100.0%	1700	65.3%	1700	66.5%
1800	81.4%	1800	100.0%	1800	70.3%	1800	71.5%
1900	89.3%	1900	100.0%	1900	77.1%	1900	78.5%
2000	95.2%	2000	100.0%	2000	82.2%	2000	83.7%
2100	100.0%	2100	100.0%	2100	87.3%	2100	88.8%
				2200	93.9%	2200	95.6%
				2300	97.9%	2300	99.6%
				2400	99.6%	2400	100.0%
				2500	100.0%	2500	100.0%

Table 39. Hot Skid Demand Table

Figures 67 through 70 reflect the discrete frequency distributions of the F/A-18C, D, E, and F respectively. There were 197 F/A-18C refueling events, 39 F/A-18D events, 162 F/A-18D events, and 131 F/A-18F events (G. Blocker, personal communication, January 16, 2013).

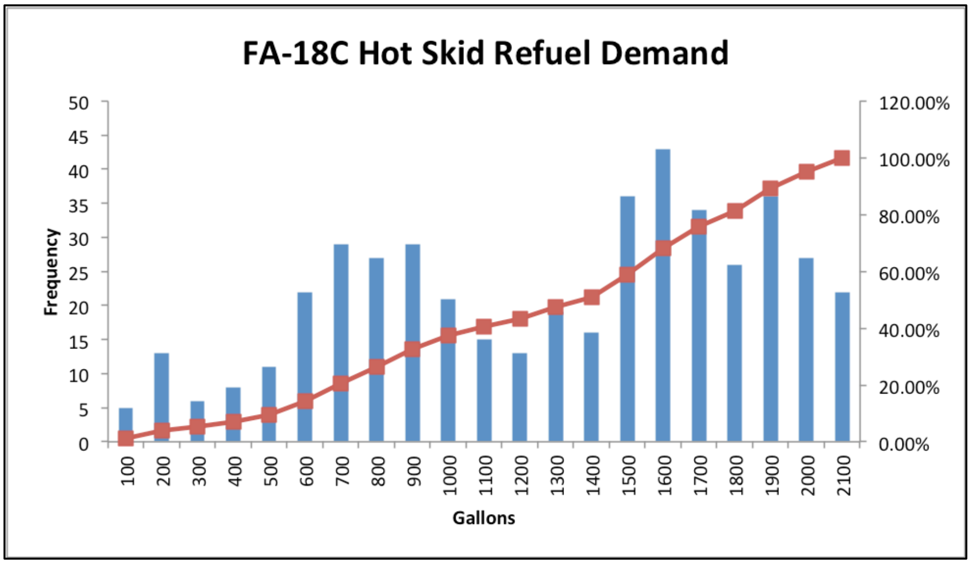


Figure 67. F/A-18C Hot Skid Refuel Demand

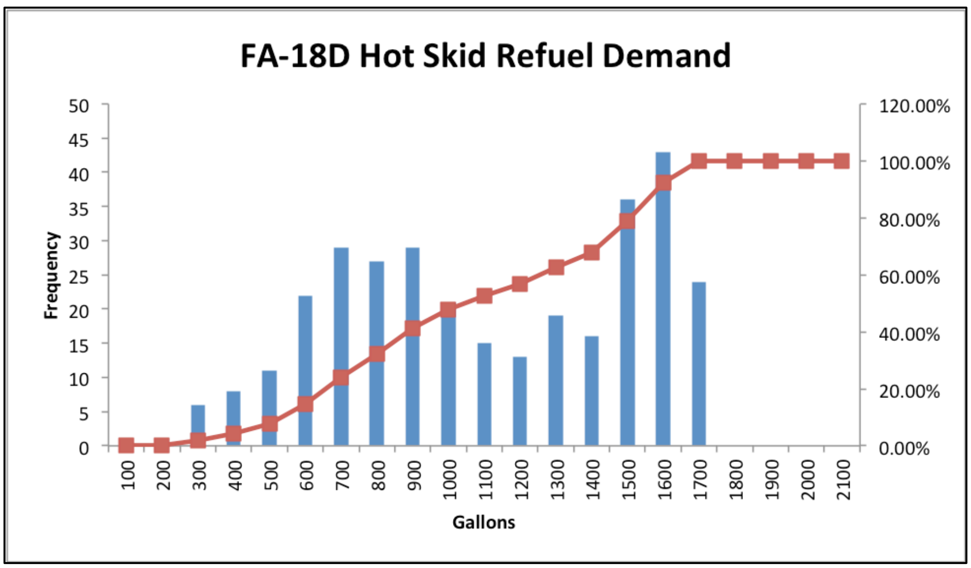


Figure 68. F/A-18D Hot Skid Refuel Demand

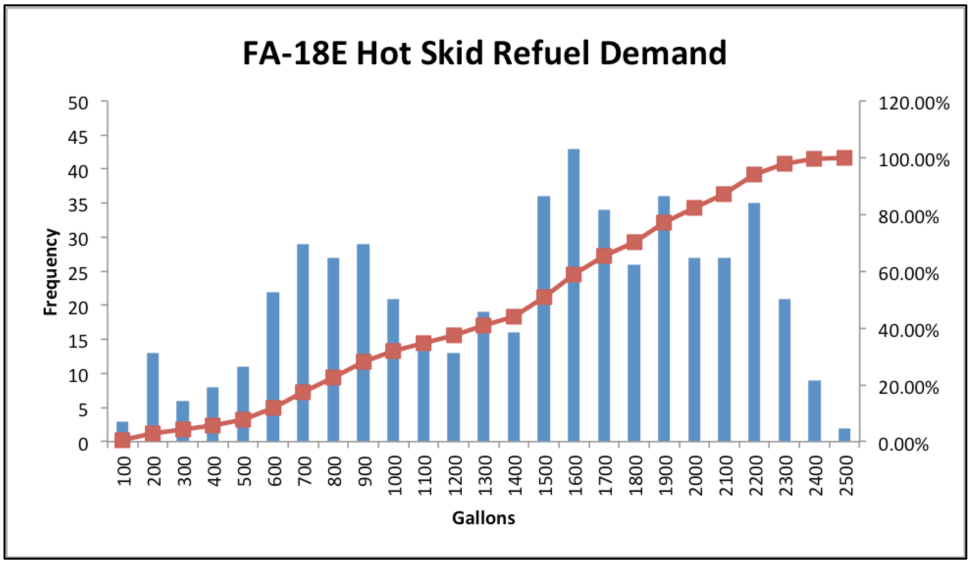


Figure 69. F/A-18E Hot Skid Refuel Demand

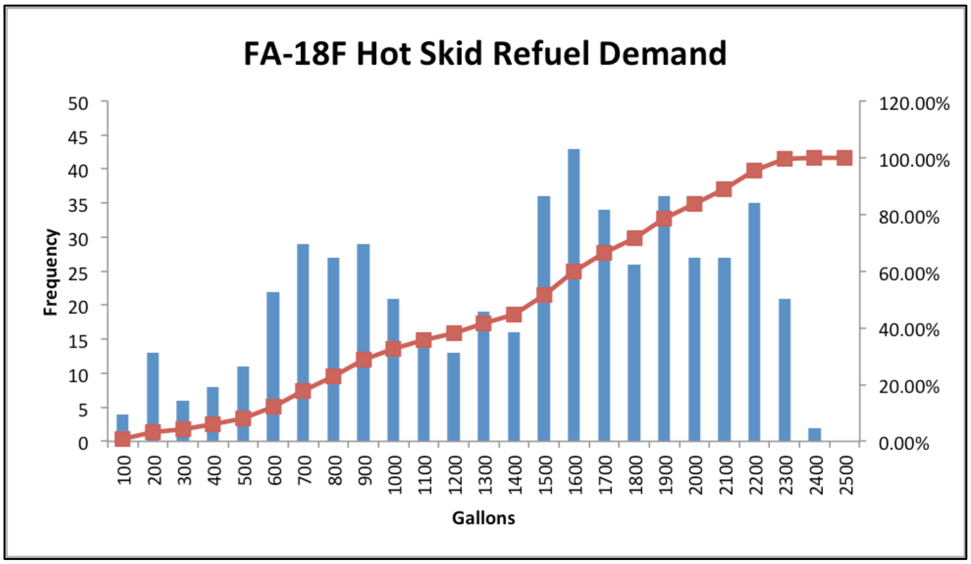


Figure 70. F/A-18F Hot Skid Refuel Demand

3. Historical Usage

Table 40 provides a summary of all successful refueling events during August 2012. Of the 4,300 refueling events in August, only 3,562 of them successfully transferred fuel via fuel truck or hot skid to or from aircraft (S. Cotta, personal communication, January 25, 2013). Table 40 abstracts from unsuccessful refueling attempts as well as ground service equipment refueling events. Our analysis suggests the ratio of fuel truck to hot skid is significantly higher than depicted when constrained to the period of 0800 to 1759. When looking only at refueling events during this 10-hour period, NAS Lemoore based aircraft planned (via flight schedule) the hot skids at an average rate of 36.9 percent (G. Blocker, personal communication, January 16, 2013). When average across the entire fly day, however, the rate drops back into the 10–25 percent range.

Refuels	Fuel Truck	Cold Skid	Hot Skid	Total	Defuels	Grand Total	Daily Cold %
1-Aug-12	142		16	158	2	160	90%
2-Aug-12	136		22	158	4	162	86%
3-Aug-12	50		7	57	0	57	88%
4-Aug-12	3		0	3	0	3	100%
5-Aug-12	30		0	30	1	31	100%
6-Aug-12	130		20	150	0	150	87%
7-Aug-12	115		45	160	3	163	72%
8-Aug-12	140		33	173	2	175	81%
9-Aug-12	127		28	155	0	155	82%
10-Aug-12	64		22	86	3	89	74%
11-Aug-12	9		0	9	0	9	100%
12-Aug-12	17		0	17	1	18	100%
13-Aug-12	92		12	104	1	105	88%
14-Aug-12	131		25	156	3	159	84%
15-Aug-12	137		11	148	2	150	93%
16-Aug-12	160		17	177	2	179	90%
17-Aug-12	47	1	24	72	0	72	65%
18-Aug-12	0	1	0	1	0	1	
19-Aug-12	57		0	57	0	57	100%
20-Aug-12	177	1	23	201	3	204	88%
21-Aug-12	206		29	235	5	240	88%
22-Aug-12	195		29	224	4	228	87%
23-Aug-12	177		25	202	1	203	88%
24-Aug-12	26		3	29	3	32	90%
25-Aug-12	9		0	9	0	9	100%
26-Aug-12	55		0	55	1	56	100%
27-Aug-12	151		54	205	4	209	74%
28-Aug-12	170		42	212	4	216	80%
29-Aug-12	151		25	176	2	178	86%
30-Aug-12	68		23	91	1	92	75%
31-Aug-12	11		0	11		0	100%
Totals	**2983**	**3**	**535**	**3521**	**52**	**3562**	**88%**

Table 40. NAS Lemoore Fuels Division Monthly Summary (August 2012)

G. HOT BRAKE CHECK

Once clear of the runway on landing, all aircraft proceed directly to one of six hot brake check processes depending on hangar assignment. The processing time in the hot brake check is standardized, however, for those aircraft identified as having ordnance onboard (average of 65 percent), their hot brake check procedure is extended one minute for de-arming by maintenance ground crew. Table 41 depicts those missions postulated to require ordnance de-arming (NAVAIR, 2012c).

Flight Events Requiring Ordnance De-arm					
TMR	F/A-18C	TMR	F/A-18E	TMR	F/A-18F
1A0	9	1A0	2	1A0	4
1A1	358	1A1	232	1A1	532
1A2	23	1A2	30	1A2	27
1A3	176	1A3	115	1A3	164
1A4	38	1A4	6	1A4	14
1A5	10	1A5	4	1A5	23
1A6	928	1A6	485	1A6	840
1A7	659	1A7	275	1A7	743
1A8	1	1A9	4	1A9	8
1A9	1	1B6	4	1B1	4
1B1	2	1B7	3	1B6	22
1B6	17	1C1	3	1B7	8
1B7	12	2J1	3	1C1	14
1C1	6	2J2	13	1C5	1
1F1	2	2K0	1	1F1	4
1I3	1	2K2	10	1G1	18
2J1	1	2K4	242	1G6	41
2J2	93	2K7	7	1G7	49
2K0	1	2K8	2	1G9	2
2K1	3	2K9	1	2J1	7
2K2	121	2L0	33	2J2	65
2K3	6	2L1	24	2K0	2
2K4	190	2L7	1	2K1	1
2K6	1	2L9	16	2K2	16
2L0	79	2Q4	8	2K4	204
2L1	6	2Q6	2	2K7	4
2L2	1	3S2	1	2L0	34
2L9	13		**1527**	2L1	16
2M6	2			2L3	1
2Q4	33			2L5	16
	2793			2L9	51
				2Q1	3
				2Q4	23
				2Q6	2
				3S2	1
					2964
64.8%	Req De-arm	66.3%	Req De-arm	64.7%	Req De-arm

Table 41. Flight Events Requiring Ordnance De-arm

H. LINE OPERATIONS

The line operations process is a model in and of itself. Contained within are the sub-processes responsible for post-flight checks, aircrew swap, engine shutdown, and aircraft sink (used on last flight of the day). Figure 71 depicts the major elements of the line operations process. Every aircraft entering the line flows through the post-flight check process and delays for two to four minutes (typically three minutes). Then, depending on satisfying one of two Boolean logic sequences, routes to either aircrew swap or engine shutdown for additional processing. The aircrew swap process time is between four and six minutes (typically five minutes) and the engine shutdown process is two to seven minutes (typically three minutes). Following aircrew swap, the aircraft flows without restriction to the marshal process where it awaits the other members of the flight. For those aircraft flowing through the engine shutdown process, either a fuel truck is requested (if scheduled to fly again) or it proceeds directly to the sink (if the last flight of the day). Figure 72 shows the line operations process as it appears in Simio.

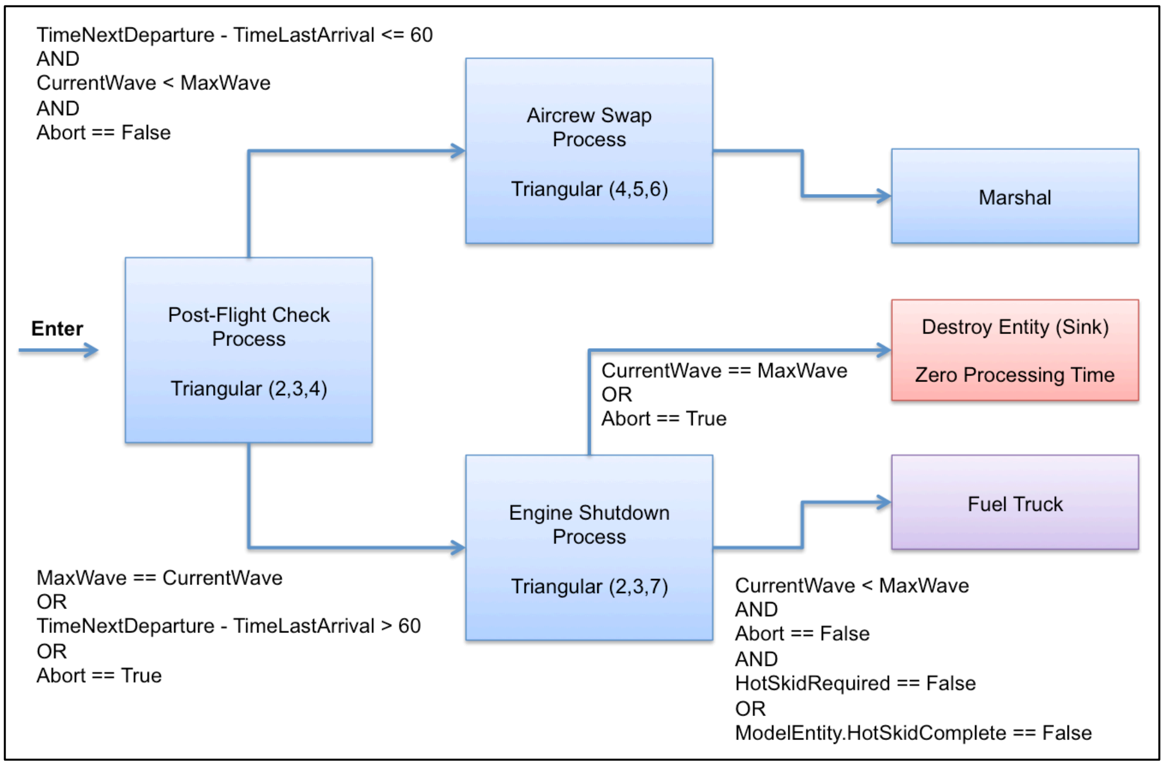


Figure 71. Line Operations Logic

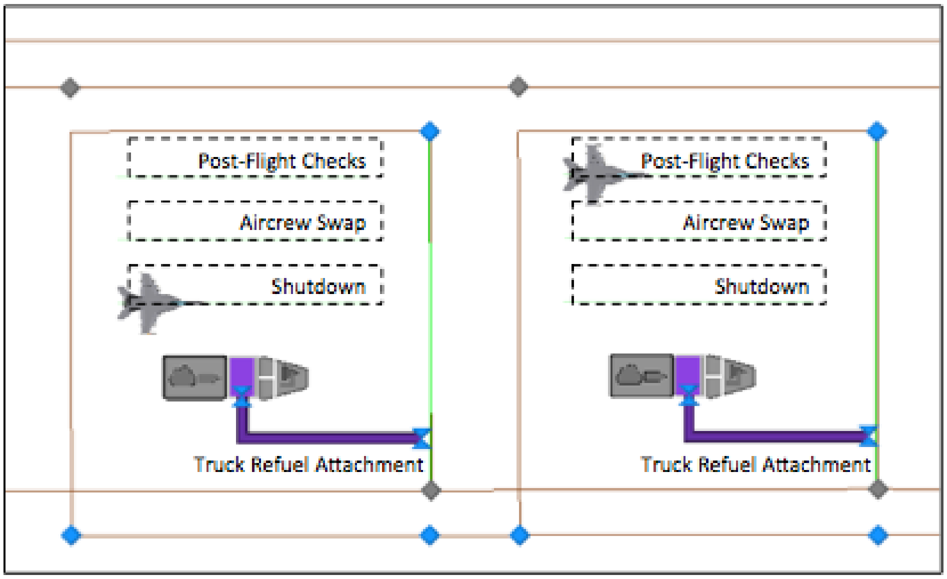


Figure 72. Line Operations (Simio screenshot)

I. HOT BRAKE CHECK

Figure 73 depicts the major elements of the hot brake check process.

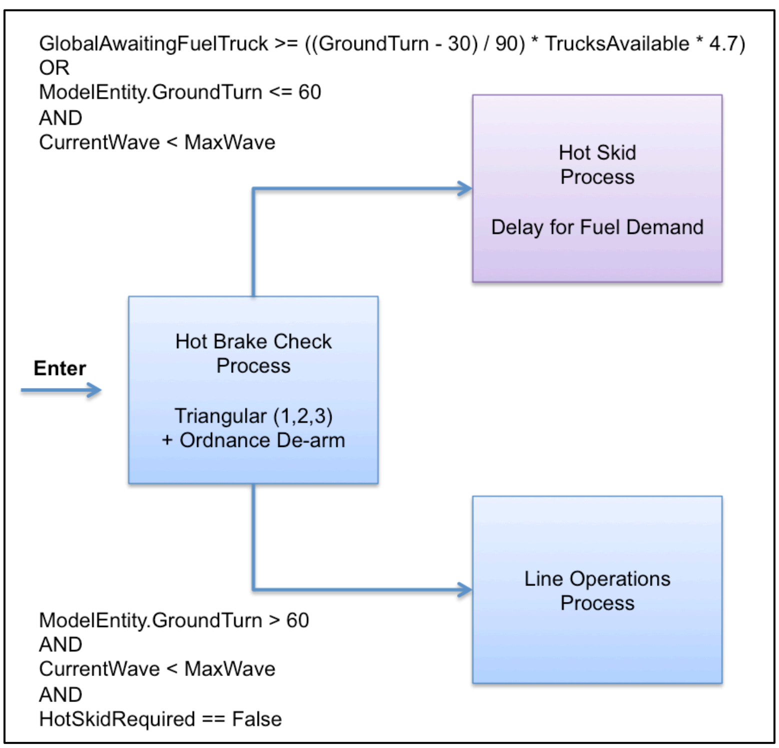


Figure 73. Hot Brake Check Logic

J. COST

Aircraft maintenance costs per minute are contained in Table 42. In calculating maintenance cost, Aviation Depot Level Repairable, consumables, and contracts are considered. Refer to Figure 74 for details of each component (M. Angelopoulos, personal communication, January 30, 2013).

US Pacific Fleet Cost Data (FY2012)								
Aircraft Type	Annual Flight Hours	Average Hourly AVDLR (FA)	Hourly Average Consumables (FM)	Hourly Average Fuel (FF)	Hourly Average Contracts (FW)	Average Cost per Flight Hour	Average Hourly Maint Cost Only	Average Maint Cost per Minute
FA-18C	22,711	$ 4,202.07	$ 1,904.55	$ 3,932.27	$ 7.06	$ 10,045.95	$ 6,113.68	$ 101.89
FA-18D	11,908	$ 4,114.44	$ 2,929.91	$ 4,066.20	$ 85.22	$ 11,195.77	$ 7,129.57	$ 118.83
FA-18E	27,877	$ 3,255.51	$ 1,304.88	$ 4,373.05	$ 41.46	$ 8,974.90	$ 4,601.85	$ 76.70
FA-18F	22,633	$ 3,495.61	$ 1,240.34	$ 4,539.40	$ 41.46	$ 9,316.81	$ 4,777.41	$ 79.62

Table 42. F/A-18 Aircraft Maintenance Cost per Minute

Table 43 reflects fuel costs per minute per aircraft using JP-5 and the Defense Logistics Agency Standard Fuel Price dated October 1, 2012 (M. Angelopoulos, personal communication, January 30, 2013; CNO, 2011a, 2012a; DLA, 2012).

GSA Standard Fuel Prices (Effective October 1, 2012)							
Aircraft Type	Fuel Flow per Engine (pph)	No. of Engines per Aircraft	Fuel Weight in Pounds (JP-5)	Fuel Flow per Engine (gph)	Fuel Flow per Engine (gpm)	GSA Standard Price (10/1/12)	Average Fuel Cost per Minute
FA-18C	600	2	6.8	176.47	2.94	$ 3.75	$ 11.03
FA-18D	600	2	6.8	176.47	2.94	$ 3.75	$ 11.03
FA-18E	750	2	6.8	220.59	3.68	$ 3.75	$ 13.79
FA-18F	750	2	6.8	220.59	3.68	$ 3.75	$ 13.79

Table 43. F/A-18 Fuel Cost per Minute

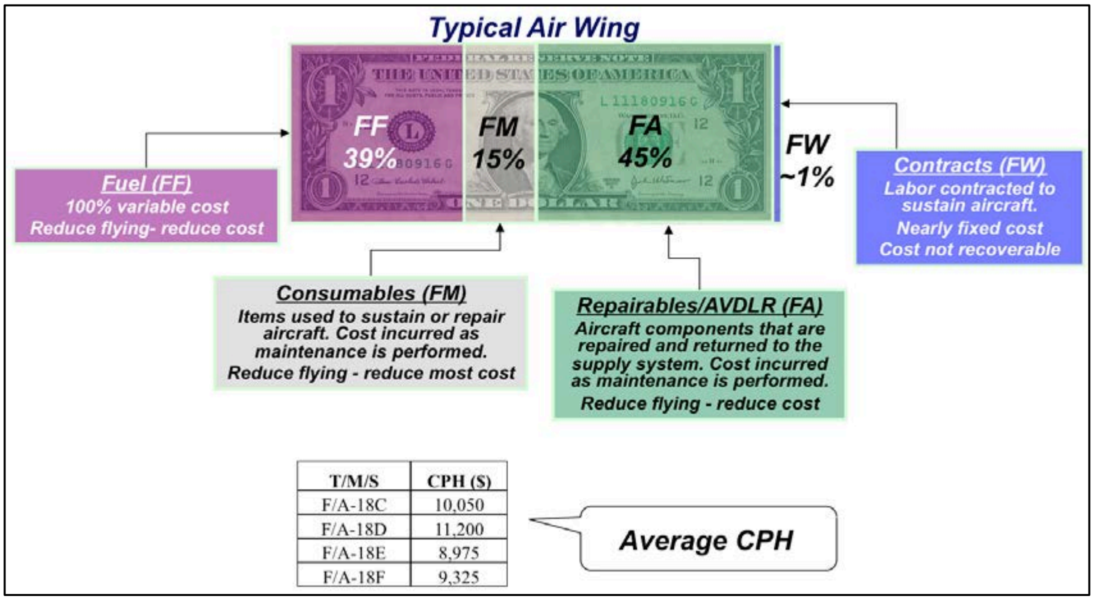


Figure 74. Cost per Flight Hour Components

K. SIMIO MODEL PROCESSES AND OBJECTS

1. Processes

Processes are used to either customize the behavior of an instantiated object (FuelTruck and ModelEntity), or to create new object definitions (HotSkidOps, LineOps, and FlightJoin). More than 50 processes were designed, implemented, and validated. Of those, most significant contributors to the model's success in mimicking the real world are included in Tables 44 through 48.

Primary and Secondary Timing Model Processes	Description
CreatingEntities	When an aircraft is first created by the simulation, this process sets the flight composition as well as establishes the planned flight schedule.
CreatedEntities	Once a flight of aircraft is created, the flight time and arrival times are updated based on historical inherent variation. If there has been an exceedance in the maximum number of aircraft allowed per hour, this process will destroy the excees aircraft.
SecondaryTiming	This process dynamically builds the flight schedule for subsequent waves.

Table 44. Primary and Secondary Timing Model Processes

Hot Brake Check Model Processes	Description
Input_Server_HotBrake_Hangar1_Entered	This process delays 65% of all arriving aircraft 1 minute for ordnance de-arming.

Table 45. Hot Brake Check Model Processes

Hot Skid Model Processes	Description
CheckHotSkid1Queue	Prior to entering the hot skid queue, this process will verify that capacity exists.
EnteredPathBackToHotSkids	If insufficient capacity existed in the hot skids after landing, the aircraft will proceed directly to the line for a crew swap. Then, proceed back to the hot skids for a second attempt. If on the second attempt, there is still insuffícent capacity, the aircraft will wait until a lane becomes available.
HotSkidEntry	Upon entering the hot skid area, this process will calculate the amount of fuel demanded based on aircraft type using a discrete cumulative probability distribution.
HotSkidLine1_Entered	This model has the ability to restrict 100% of the hot skids, 50% of the hot skids, or allow no restrictions at all. Assuming the hot skids are in operation, this process helps direct aircraft based on their refueling status, crew swap status, last flight of the day status, and aircraft maintenance status (Up or Down).

Table 46. Hot Skid Model Processes

Fuel Truck Model Processes	Description
BypassFuelTruckDelay	When the hot skids are used in lieu of a fuel truck due to insufficient fuel truck capacity, this process is invoked to hold an aircraft in the hot skid queue until a lane becomes available.
FillStandProcessNode	When a fuel truck's remaining fuel capacity is less than 2500 gallons, the truck is directed to refill. Until the truck is refilled, the truck is removed from the pool of available resources.
SeizeTruck1	When an aircraft requires refueling by fuel truck, this process requests a fuel truck and, upon arrival, transfers the required amount of fuel based on aircraft type using a discrete cumulative probability distribution.
StartTime	This process starts timing necessary to track and record an individual fuel truck's utilization. It starts when the fuel truck departs the truck staging area.
StopTime	This process stops timing necessary to track and record an individual fuel truck's utilization. It stops when the fuel truck either returns to the truck staging area or enters the fillstand for a refill.
TempReleaseState	When truck refuling is complete in the line area, this process releases the fuel truck resource to the next aircraft demanding fuel in its allocation queue, or returns to fuel truck staging area.
Vehicle_EvaluatingSeizeRequest	Prior to authorizing a truck fuel dispatch request, this process determins truck availability.
Vehicle_Released	When a fuel truck is complete servicing an aircraft, this process will update a global variable with the amount of fuel remaining in the truck.
Vehicle_RunInitialized	Prior to running the simulation, this process instantiates the fuel trucks and sets their internal and maximum fuel states.

Table 47. Fuel Truck Model Processes

Miscellaneous Model Processes	Description
ArrivalCounterUpdateFromPrimary	When an aircraft arrives from its first wave, this process will update the arrival hourly counters and ensure the maximum aircraft arrival table is complied with.
ArrivalCounterUpdateFromSecondary	When an aircraft arrives from a subsequent wave, this process will update the arrival hourly counters and ensure the maximum aircraft arrival table is complied with.
CreatedFlightSeparation	Following an abort in Marshall, typically due to failing to takeoff within 20 minutes of the aircraft's schedule departure, this process puts a short delay in to separate aircraft taxiing out as a foreign object damage control measure.
DestroyHourlyExceedance	If the number of arriving aircraf exceeds the maximum allowed for that particular hour, this process will destroy that aircraft before any statistics are recorded. If the lead aircraft was destroyed in a multi-aircraft event, the lead responsibilities are shifted to one of the wingmen.
GlobalIdleAircraftStartTiming	An aircraft exiting the line for a follow-on wave will start the clock for ground idle operations using this process.
GlobalIdleAircraftStopTiming	An aircraft landing on its last flight of the day, aborting, or otherwise is unable to make the next scheduled launch will invoke this process to stop the clock for ground idle operations.
OnRunInitialized	When the simulation commences, this process ensures that various state variables are set to an initial state.
RecordAbortTally	Monitors the number of aircraft aborting for maintenance, insufficient fuel, launch, or aircraft 20 minute beyond their planned departure time.
Reset Counters	Resets the counter logic every hour, on the hour, to ensure the maximum arrivals per hour are compled with.
UpdateTallyHourStatistics	Updates the tally statistics for arriving aircraft per hour.
FinalCheckDelay	Following hot skid refueling and prior to takeoff on a subsequent wave, each aircraft is required to delay for final checks with ground crew for 3 minutes.

Table 48. Miscellaneous Model Processes

2. Objects

SIMIO is an object-oriented approach to modeling. In modeling NAS Lemoore's airport operations, several sub-models were combined to form a larger model representing the physical components of the systems. Each object, or model, created has its own properties, states, behavior, and relationship with other objects.

Each object outlined in Tables 49 and 50 has its own behavior customized to meet the requirements of this implementation. For example, each flight line is built by placing objects that represent post-flight checks, aircrew swaps, engine shutdowns, while each hot skid consists of objects representing JP-5 fuel, the fuel hose and nozzle, as well as fuel container.

Model Objects	Quantity	Description
Primary_Source (Source)	1	Responsible for generating Wave 1 aircraft per the Squadron probability table, building the flight schedule, and destroying aircraft if there is an exceedance of the maximum allowable per hour.
Server_HotBrake_Hangar1 (Server)	6 One for each hangar. Hangar 5 has two.	Responsible for conducting hot brake checks, canopy electrostatic discharge, and when appropriate, de-arming. The time required is specified using a triangular distribution plus 1 minute for de-arming when required.
HotSkidOps (Filler)	20 Four for each hangar.	Responsible for refueling aircraft with the engines online. The time required is determined by fuel demand and fuel flow rate from the hot skid. This model assumes the external fuel tanks are refilled at 120 gpm and internal fuel cells at 200 gpm. A minute has been added for chocks, fuel cap removal, and fuel hose attachment.
LineOps	188 One for each spot.	All aircraft enter the line operations process regardless of status. The first step is the Post-Flight Checks process involving chocks and/or chains, securing equipment, talking with troubleshooters, etc. This model assumes the processing time as Triangular (2,3,4). The next step is to branch into the Crew Swap process or Engine Shutdown process depending on the requirements of the flight schedule and ground resource capacity. Crew Swap processing time is Triangular (4,5,6) and Engine Shutdown processing time is Triangular (2,3,7).
Filler (Fuel Truck refueling process)	188 One for each spot.	Responsible for refueling aircraft in the line (engines offline). The time required is determined by fuel demand and fuel flow rate from the hot skid. This model assumes the external fuel tanks are refilled at 120 gpm and internal fuel cells at 200 gpm.

Table 49. Model Objects

Model Objects (continued)	Quantity	Description
FlightJoin (Marshal process)	20 One for each line.	Responsible for assembling flight members back into a single flight. Regardless of refueling source and crew swap requirements, this process combines the individual aircraft into a single flight.
Abort (Server)	5 One for each hangar.	Responsible for monitoring the abort status of aircraft. If a flight fails to launch within 20 minutes of their schedule departure, this object will separate the flight from its combined status back into individual aircraft for routing back to the line to shutdown.
Secondary_Separator (ServerInflightDelay)	1	Responsible for managing aircraft on their second and subsequent waves by building the flight schedule, updating statistics, forecasting future aircraft arrivals, and destroying aircraft if there is an uncontrollable hourly exceedance.
Paths	1,219	There are two network paths, one for aircraft and another for fuel trucks. Some paths are unidirectional and other bidirectional. Each pathway has a fixed length measured in feet as well as a rate of travel facilitating the time an aircraft spends at ground idle.
Connectors	451	Connectors are used throughout the model to facilitate the movement of aircraft and ground resources in zero time. There are no distances associated with connectors or other statistics material to the model.

Table 49. Model Objects (continued)

APPENDIX B. CDM TOOLBOX

A. CDM APPLICATIONS

1. SHARP: An Operational DSS

In 1992, Warren E. Walker of RAND Corporation published a journal article outlining changes in organizational structure through enhancements in information technology. In both the commercial and military sector, many large organizations are transitioning from highly centralized decision-making to networks of distributed centers of excellence (Walker, 1992). Advances in computer technology have made it possible to rapidly communicate across wide geographical area in support of mutually defined organizational goals and objectives. What was once a single decision maker at a standalone computer is now benefiting from the rapid exchange of information using a common set of network tools in an operational decision support system (ODSS) (Walker, 1992).

The benefits of decentralized decision making are widely accepted in organizational behavior literature and in industry (Merchant & Van der Stede, 2012). Specifically, decentralization empowers employees in a way that leads to increased job satisfaction and productivity and lower rates of job turnover. From an efficiency perspective, decentralized decision authority significantly decreases the time it takes a particular decision to be executed. Furthermore, decentralization improves the quality of the final decision by embracing stakeholder innovation, creativity, and flexibility necessary at lower levels in the operational hierarchy (Merchant & Van der Stede, 2012).

According to Walker, operational decision support systems facilitate centralized support for decentralized organizations (1992). To be successful, organizations must fully support ODSS implementation. Political interference is one of the main reasons improvements in efficiency and effectiveness are slowed. Other barriers to reach fruition include data consistency (data format), organizational structure, and model output appropriate for the decision being made (Walker, 1992).

The ODSS Walker recommends consists of five key elements: users, models, data, network, and use cases. Fortunately for Naval Aviation, this elaborate information technology already exists in the form of SHARP (Sierra Hotel Aviation Readiness Program). SHARP is a web-based application used by all aviation squadrons to track readiness, flight scheduling, budget data (Flying Hour Program) and generate summary reports. Therefore, no new management information system requires development. SHARP is capable of providing a unified organizational approach to solving capacity and demand management problems across a given flight line. However, current squadron scheduling processes do not take advantage of this functionality thus leading to a myopic approach to flight operations. All five elements Walker recommends of an ODSS are available in SHARP. What is lacking, however, is the political willingness to change existing flight scheduling techniques and procedures. Doing so would enhance information exchange not only between individual squadrons, but also with base operations (air traffic control and fuel services) and range management offices.

2. Aircraft Carrier Air Plan Model

In 1992, Robert Stammer studied DSS implementation afloat. His research efforts responded to a CNO directed tactics development and evaluation (TAC D&E) with a database approach to aircraft carrier air plan production (Stammer, 1992). The air plan is a collaborative planning and execution document for daily flight operations. Every aircraft carrier operating at sea today is responsible for producing a daily air plan. Until the mid-1990s, however, each aircraft carrier used a different technique in doing so (Stammer, 1992).

Stammer's research addressed a significant problem in the Navy's aircraft carrier community. Inefficiencies in the daily air plan production process resulted in decreased productivity and combat effectiveness (Stammer, 1992). Embarked in an aircraft carrier are hundreds of principal aviation stakeholders, each of whose voice must be reflected in the daily air plan. The TAC D&E highlighted three main objectives for Stammer address: 1) develop a strategy for analyzing the current process; 2) identify quantitative metrics for objective plan development; and 3) automate the process (Stammer, 1992).

In response to the TAC D&E objectives, Stammer analyzed afloat air operations and the interactions between the ship and embarked air wing. He concluded four basic variables frame a day's flight operations: number of day cycles, number of night cycles, total number of sorties, and the time flight operations will commence and terminate (1992). These attributes form the foundation for the daily air plan. Stammer also established a system of priorities among the various stakeholders. This system ensures the operational objectives of individual stakeholders are captured and compliant with the greater carrier strike group's objectives.

With a thorough understanding of the process and performance metrics, Stammer then addressed the final TAC D&E objective by creating an automated system to standardize daily air plan production. This thesis developed a prototype system using a multi-purpose, commercially available, off the shelf program that was already in use in aircraft carriers (Stammer, 1992). This approach significantly reduced the cost of implementation and leveraged the knowledge that end users already possessed. Stammer's understanding of metrics, stakeholder priorities, and operational constraints led to the creation of a functional database prototype. This prototype was successfully tested in an operational environment onboard USS ABRAHAM LINCOLN (CVN 72).

A significant gap in Stammer's research was cultural change. In his final analysis, he concedes the majority of air plan production problems were not with development, but rather stakeholder's failing to communicate effectively throughout the ship (Stammer, 1992). Therefore, technology can go a long way toward improving efficiency and synergy, but without leadership buy-in and incentives to work toward a common vision, no DSS will succeed (Merchant & Van der Stede, 2012).

Although this thesis concentrated entirely on air plan production afloat, these concepts can easily apply to the land-based flight scheduling process. As many differences as there are in flight operations afloat and ashore, there are an equal number of similarities. The aircraft carrier uses predictable aircraft launch and arrival times orchestrate hundreds of activities from logistics and navigation to engineering and maintenance. The keyword is *predictability*. When these same squadrons operate ashore, they operate whenever they desire within the constraints of the field hours.

Furthermore, with minimal collaboration between squadrons and no concern for delays in takeoff, landing, and post-flight refueling resources, the Navy's vision to foster a culture of fuel conservation cannot be realized. Implementing a similar wing-wide scheduling process ashore would be one way of implementing an airfield slot management system for arriving aircraft.

3. Surface Movement Advisor

The Federal Aviation Administration (FAA) commissioned an integrated product team in 1998 to develop a decision support system proof-of-concept capable of managing aircraft ground delays (Lawson, 1998). During periods of high traffic volume, the so-called "Surface Movement Advisor" (SMA), would share large amounts of relevant information among airlines, airport operators, and air traffic controllers thus increasing both speed and quality of operational decisions. Furthermore, this information enhances the situational awareness of decision makers to better respond to airfield capacity limitations and lead-turn excessive aircraft ground delays before they manifest (Lawson, 1998).

The integrated product team was led by the FAA and collaborated with the National Aeronautics and Space Administration (NASA) and MITRE Corporation's Center for Advanced Aviation System Development (CAASD). This highly capable team aggressively pursued a host of collaborative decision making tools to reduce ground delays in response to increased airfield congestion (Lawson, 1998). SMA is the result of their research and analysis. SMA brings together the principal stakeholders responsible for managing aircraft from touchdown to "gate-in" (engine shutdown). As queues develop from aircraft clearing the runway on taxi-in and at terminal gates, decisions made to change runway utilization, taxiway routing, and aircraft departure procedures alleviates congestion to reduce delays (Lawson, 1998). The SMA proof-of-concept was an overwhelming success. One of the objectives was to reduce taxi time by one minute per aircraft. The results of the 90-day beta test at Hartsfield-Jackson Atlanta International Airport revealed a taxi time reduction of over two minutes per aircraft.

The integrated product team developed the SMA software suite using existing commercial off the shelf hardware and software packages. This architecture then interfaced with the "National Airspace System (RADAR tracks, flight information), airline data (Flight Information Display System (FIDS)), electronic Official Airline Guide (OAG), and airport/ramp tower" taxi, takeoff, and landing data (Lawson, 1998). In total, there were 19 SMA displays installed at the Atlanta test site. All users, regardless of station, saw the same information, on the same screens, in the same format—they all literally played from the same sheet of music (Lawson, 1998).

SMA's graphical user interface divided data into three main categories: air traffic control tower data, airport/ramp management data, and airline data. The requisite data was captured in real-time by the various stakeholders and presented by the SMA software suite. In similar fashion, the U.S. Navy could benefit greatly from the sharing of such information. Currently, there is no such management information system linking together ATC, base operations, wing operations, and squadrons. Furthermore, each airfield stakeholder collects data in a variety of independent databases, most of which could easily be migrated to a web-based application for collaboration and sharing. It is from this backdrop that SMA provides valuable insight into the successes realized by the airline industry. These same efficiencies could also benefit Naval Aviation in one form or another.

4. Implications of Military DSS

In 2005, the RAND Corporation published *Implications of Modern Decision Science for Military Decision-Support Systems*, an objective analysis of modern collaborative information systems within the DoD (Davis, Kulick, & Egner, 2005). Their research provides a brief overview of decision support systems (DSS) as well as insight to the complexities of higher-level decision-making. Furthermore, the article solidifies the requirement for increased collaboration between higher-level and operational decision makers in achieving efficient operations.

According to the RAND study, when individual decision makers understand how their actions fit into the larger process, there is increased synergy between management at all levels (Davis et al., 2005). Furthermore, evaluating a system from an individual's perspective reveals structural and communication barriers that impede performance and efficiency. Removing organizational barriers, as viewed from the individual, results in goal alignment and congruence throughout an organization (Davis et al., 2005).

The main attributes working for or against any decision maker are inputs, strategy, and policy (Davis et al., 2005). Understanding how each of these components affects the ultimate decision made is necessary for process improvement. Therefore, with a thorough understanding of a system and the policies that support it, an organization can begin to develop and implement a DSS (Davis et al., 2005). This RAND study provides a system framework outlining the necessary data that must be considered in any DSS implementation. Of particular interest is the recommendation to flatten an organization's operational decision structure to more rapidly get critical information in the hands of the decision maker. Moving from a bureaucratic (vertical) structure to a flat (horizontal) structure is well known to improve communication and information exchange (Merchant & Van der Stede, 2012).

The RAND study provided a sound framework with emphasis on implementation in a DoD environment. This MBA project applies RAND's three decision components (inputs, strategies, and policies) to naval air installations in the form of a collaborative decision-making tool, or DSS. Any proposed DSS system must be easy to configure, navigate, and tailor to maximize interactivity all under a veil of a common language, terminology, and objectives (Davis et al., 2005). Increasing efficiency through collaboration, mutual understanding of each stakeholder's strengths and weaknesses, and operational synergy across the flight line may yield significant fuel and cost reductions. Focusing on the efficient use of ground resources through air operations management in a collaborative environment is the goal of this research.

5. Range Scheduling DSS

Decision support systems (DSS) are increasingly commonplace among military organizations. Resource managers today benefit greatly from having immediate access to a large amount of information necessary in making informed operational decisions. In

2001, the RAND Corporation performed a study for the U.S. Air Force on managing airspace and training range usage through the use of a DSS. Their comprehensive analysis of range usage included operational requirements, training tasks, required airspace characteristics, and minimum time required to achieve training objectives (Robbert, Carrillo, Kerchner, & Williams, 2001).

According to the RAND study, end user requirements are best satisfied when range parameters are linked in a relational database (Robbert et al., 2001). Prior to implementing the database, the Air Force took a deficiency-based approach to range prioritization. This approach simply matched training requirements with range capabilities (Robbert et al., 2001). Unlike the former approach, this relational database greatly enhanced decision making by speeding requirements-range pairing and ensuring ranges were not double-scheduled.

Collaborative decision-making tools such as this relational database are becoming increasingly common. As this 2001 RAND study shows, the sharing of information and standardizing training requirements and range capabilities led to increased Air Force training and readiness. Furthermore, the information technology solution in this case was not only easy to install and operate, but it was built using existing Air Force hardware and software infrastructure thus keeping costs low. This MBA research project also seeks an IT solution to share critical operational information in near real-time using existing computing infrastructure within the Navy. Bringing together a host of geographically separated stakeholders in a common framework may lead to similar increases in situational awareness and operational efficiency across the flight line.

B. CULTURAL CHANGE CHALLENGES AND OPPORTUNITIES

Secretary of the Navy Raymond Mabus established several aggressive energy goals for the Navy to achieve by the year 2020 (DON, 2012). The single largest user of the Navy's fuel resources, Naval Aviation, stands most affected by any energy policy. To that end, the aviation community is directed to adopt energy efficient practices, technologies, and operations. A critical element in changing the way Naval Aviation operates is support from senior military leaders to foster a culture of energy conservation.

The best energy policies from a research point of view often fail in practical application because of the inability to garner support both up and down the chain of command. Naval Aviation in particular has a very strong organizational culture making it resistant to change (Merchant & Van der Stede, 2012). Dr. John Kotter, a former Harvard professor and current Chief Innovation Officer at Kotter International, is a leader in the field of change management. Kotter claims that 70 percent of all major change initiatives fail (2013). In response to this assertion, he developed a highly successful *8-Step Change Model* to help organizations survive and prosper in a rapidly changing environment (Kotter, 2013).

In 2012, a team of MIT graduate students from Sloan School of Management formed at the request of the Navy (Alexeyev, de Frutos, Finicane, & Shimazu, 2012). These researchers developed a roadmap to assist Naval Aviation in the implementation of improved energy practices. Naval Aviation is deeply rooted in tradition making any organizational or structural change difficult to realize. Their study incorporated surveys and interviews of both maintenance and operations personnel. The results revealed a greater resistance to change among operations personnel than maintenance technicians (Alexeyev et al., 2012). The most significant claim by those in operations was the belief that energy conservation could only come at the expense of readiness and tactical proficiency (Alexeyev et al., 2012). Furthermore, many operators interviewed felt as though Naval Aviation is already minimizing fuel resources. Unfortunately, perception management is yet another leadership challenge.

As fiscal and operational pressures intensify, the leadership should anticipate an increase in resistance cultural and procedural change. This MBA project focuses explicitly on the ground operations occurring post-flight. The event landing time represents the end of the tactical or administrative mission. Therefore, by focusing entirely on the process between touchdown and engine shutdown, operational personnel should be more inclined to adopt energy efficient policies. The proposed slot management system in this report is just one way to balance squadron demand for airfield refueling resources.

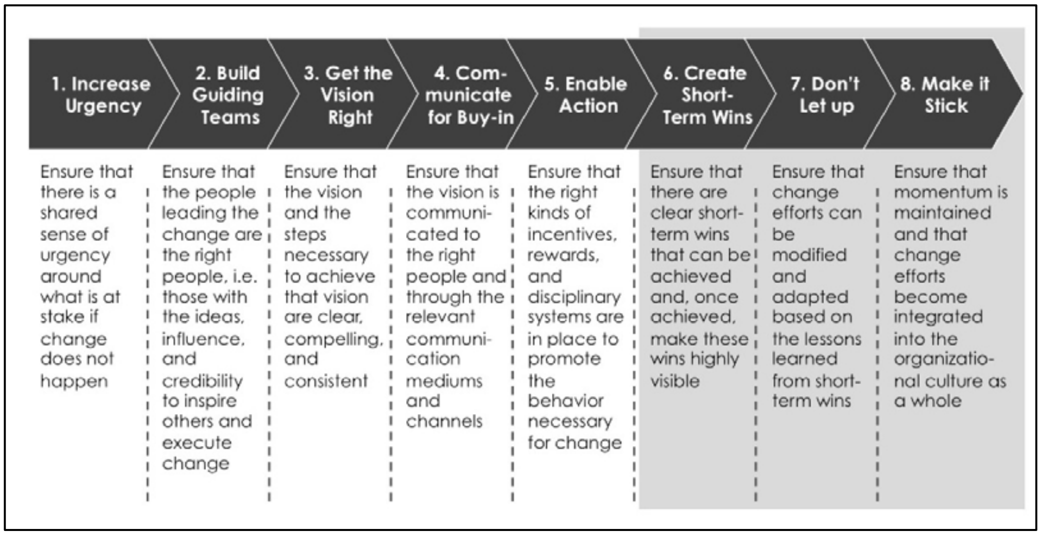


Figure 75. 8-Step Change Model (From Kotter & Cohen, 2002)

To combat resistance to change, the MIT study proposed a solution using the eight-step framework outlined in *The Heart of Change* (Kotter & Cohen, 2002). Where the MIT study addresses the first five steps, our MBA project offers solutions commencing from that point forward (Figure 75). A key to enabling action is breaking down barriers to communication that prevents people from carrying out the vision. In the Navy's case, that vision is improved energy conservation. The largest barrier to overcome is in flight scheduling. Each commanding officer orchestrating his schedule without regard to operations across the airfield introduces unwanted variability in the arrival of aircraft. This variability, in turn, creates ground delays, which increases fuel consumption and generates waste. Finding ways to create "short-term wins" to pave the way toward permanent change is a necessary step to ensuring the health of the Fleet.

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APPENDIX C. SIMIO DOCUMENTATION REPORT

For a complete Simio documentation report of the model, please visit the following links to the online supplement. Two file formats are provided.

Online Supplement (HTML format)
https://www.dropbox.com/s/2ejpj2a4qvns0k1/Appendix%20C%20-%20Simio%20Documentation%20Report.html
Size: 8.12MB

Online Supplement (PDF format)
https://www.dropbox.com/s/3usj7n2b8s1rez9/Appendix%20C%20-%20Simio%20Documentation%20Report.pdf
Page Count: 1,050

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